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SENSITIVITY AND FEASIBILITY ANALYSIS OF GREAT LAKES/ST. LAWRENCE SEAWAY CAPACITY EXPANSION MEASURES TO THE YEAR 2050

TASK 8.5 Report of Great Lakes/St. Lawrence Seaway Regional Transportation Studies

Prime Contract DACW 35-80-C-0060

September 1981

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Submitted to

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North Central Division, Corps of Engineers
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This report documents the results of a sensitivity and feasibility analysis of capacity expansion measures for the Great Lakes/ St. Lawrence Seaway System. Non-structural and structural alternatives for increasing the capacity of the system were simulated in an effort to identify possible modifications to the GL/SLS System, which would pass the projected 2050 unconstrained commodity flows.

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1. SUMMARY

This report documents the results of a sensitivity and feasibility analysis of capacity expansion measures for the Great Lakes/St. Lawrence Seaway System. Non-structural and structural alternatives for increasing the capacity of the System were simulated in an effort to identify possible modifications to the GL/SLS System which would pass the projected 2050 unconstrained commodity flows.

The GL/SLS Lock Capacity Model was used to perform the simulations. The previously existing model was modified to test for lock capacity, defined as an average lock utilization greater than or equal to 90% for the period May through November, and to implement non-structural and/or structural capacity expansion measures when capacity was reached. Modifications were also made to allow input of up to 15 commodities. The GL/SLS Lock Capacity Model has been validated at the Soo, Welland Canal, and St. Lawrence River Lock Systems using 1976 data.

As a first step in the analysis, the simulation was run with the lock systems using existing conditions to determine when capacity would be reached. With existing high water levels permitting drafts of 27 feet at the Soo and 26 feet at the Welland Canal and St. Lawrence River, capacity would be reached in 1984 with 78,926,000 short tons at the Welland Canal, in 2010 with 182,251,000 short tons at the Soo, and in 2014 with 99,174,000 short tons at the St. Lawrence River Locks. Using the low water datum draft of 25.5 feet throughout the system, capacity would be reached in 1981 with 75,198,000 short tons at the Welland Canal, in 2006 with 173,739,000 short tons at the Soo, and in 2006 with 92,526,000 short tons at the St. Lawrence River Locks.

Four individual non-structural alternatives were tested for their effectiveness in increasing system capacity. These four alternatives are:

1. Installing traveling kevels,
2. Increasing ship speed into the lock,
3. Decreasing chambering time by decreasing dump/fill time and providing downstream longitudinal hydraulic assistance, and
4. Installing a local traffic control system at each lock system.

A fifth simulation run was made using the combination of these non-structural alternatives which gave the largest locking time reduction. This combination reduced locking times 13% and consisted of installing traveling kevels, reducing dump/fill times, and installing local traffic control systems. The results of the non-structural capacity expansion analyses, in terms of the year at which capacity is reached and the corresponding tonnage processed, are shown in Figure 1.1 for the Soo Locks, Figure 1.2 for the Welland Canal, and Figure 1.3 for the St. Lawrence River Locks.

Four structural scenarios were modeled to test their ability to pass the projected 2050 unconstrained cargo flows. Two of the scenarios involved constructing larger locks able to pass Class 11 ships and to pass Class 12 ships, respectively. The other two scenarios involved deepening system-wide draft to 28 feet and to 32 feet without changing the existing lock dimensions. Each of the structural modifications was implemented after capacity was reached using the combined non-structural alternatives. The results of the capacity simulations of the structural scenarios are also shown on Figure 1.1 for the Soo Locks, Figure 1.2 for the Welland Canal, and Figure 1.3 for the St. Lawrence River Locks.

A fifth structural scenario was modeled to determine the effectiveness of constructing another large lock at the Soo without structural modifications to either the St. Lawrence River or the Welland Canal Locks. Cargo flow through the Welland Canal was limited to the near capacity tonnage of 87,400,000 short tons per year achieved with the combined non-structural alternatives. The Soo and St. Lawrence River cargo flows were re-projected based on this constraint. A new lock capable of handling Class 11 ships was built at the Soo when capacity was reached there with the combined non-structural alternatives. This new lock proved to be very beneficial as can be seen on Figure 1.1.

Capital and increased annual operation and maintenance costs were estimated for each of the non-structural alternatives and the structural scenarios. These cost estimates, although very preliminary in nature, can be used to determine the relative cost effectiveness of each alternative in this feasibility analysis.

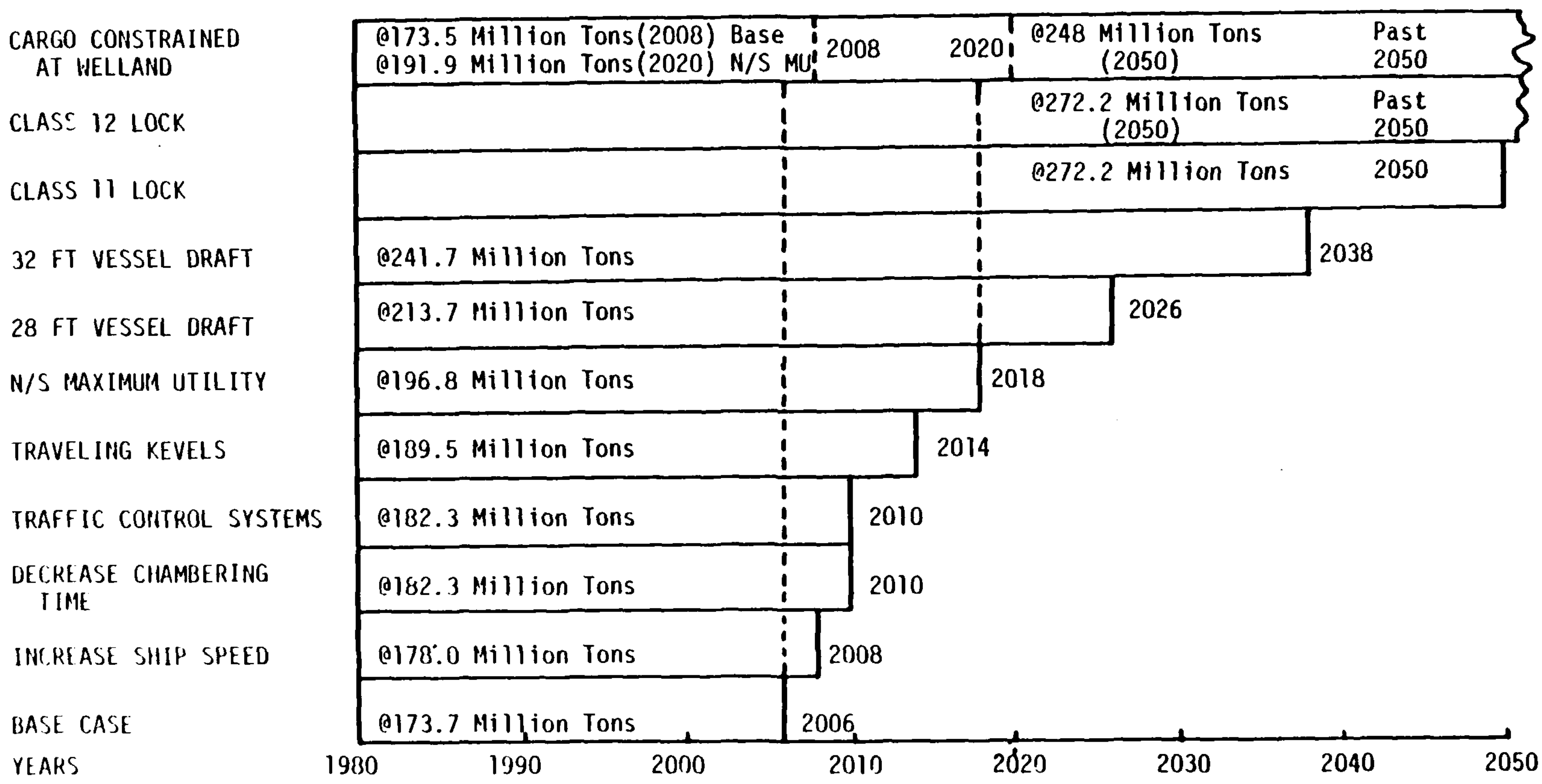


FIGURE 1.1 LOCK CAPACITY SUMMARY AT THE SOO LOCKS

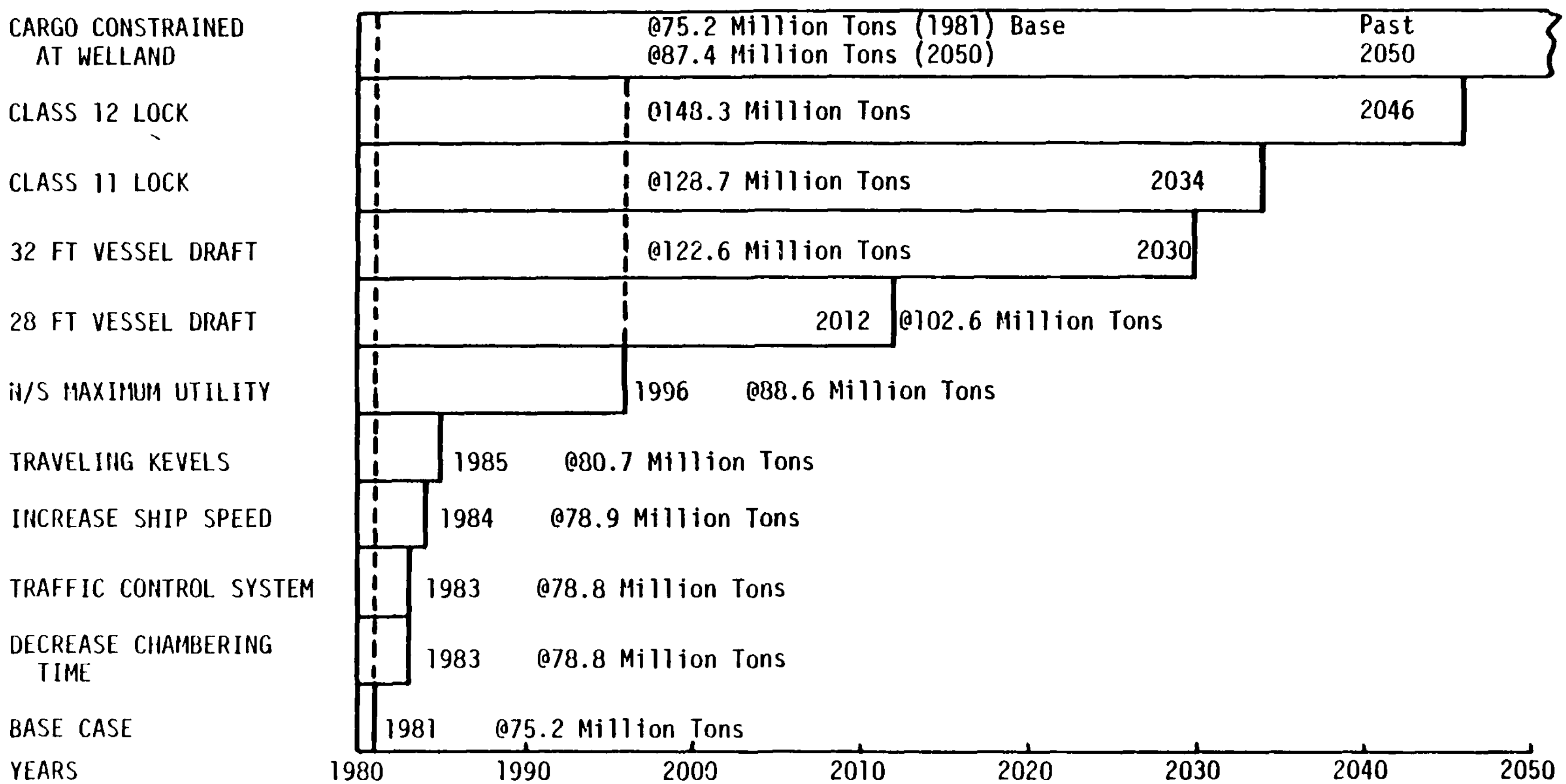


FIGURE 1.2 LOCK CAPÂCITY SUMMARY AT THE WELLAND CANAL

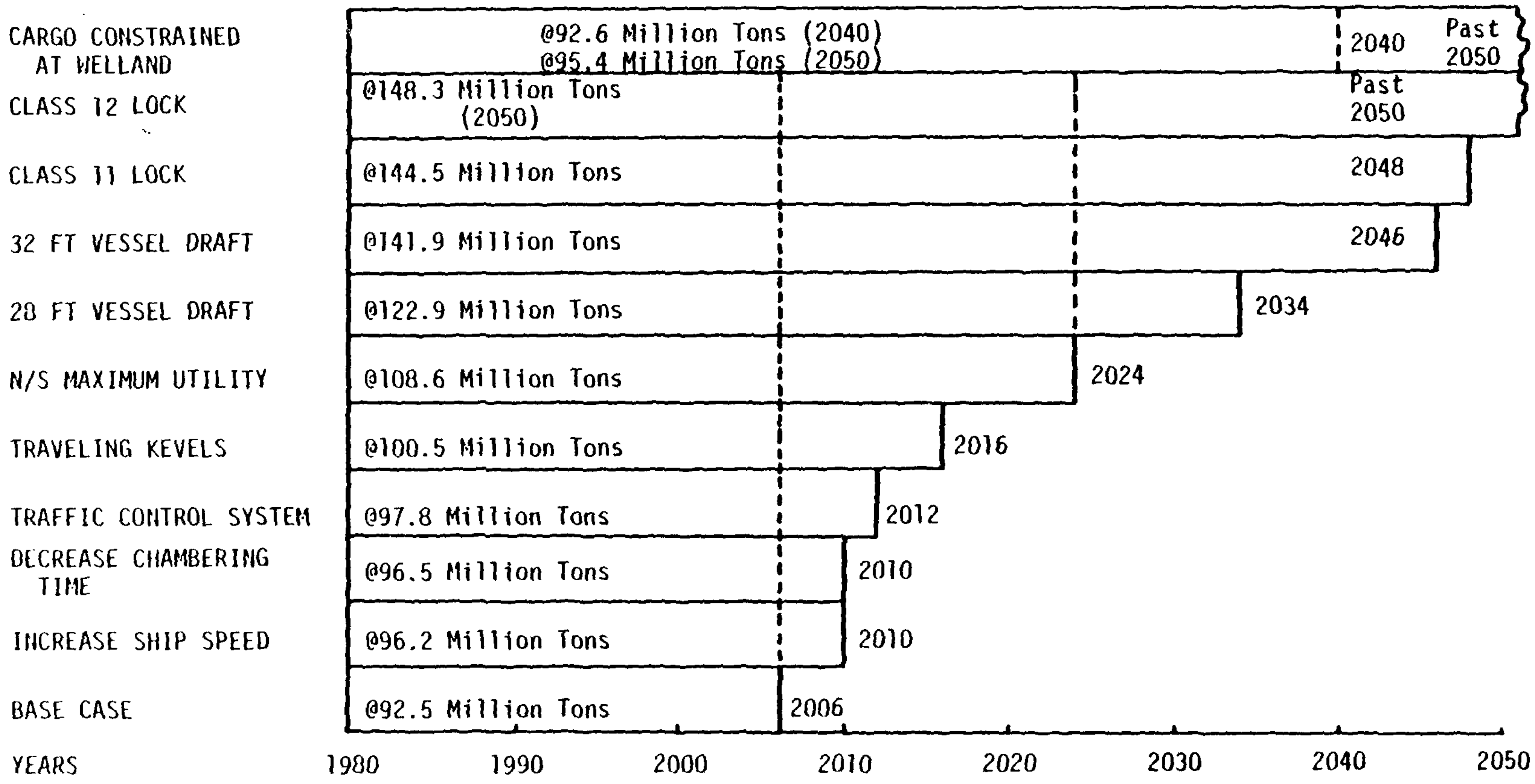


FIGURE 1.3 LOCK CAPACITY SUMMARY AT THE ST. LAWRENCE RIVER LOCKS

It is recommended that the GL/SLS Lock Capacity Model continue to be used to provide further insight into the relative merits of possible alternatives for relieving capacity conditions in the GL/SLS System. Suggestions are made for both additional sensitivity analyses of non-structural alternatives and for additional feasibility analyses of structural scenarios.

2. INTRODUCTION

The Great Lakes/St. Lawrence Seaway (GL/SLS) System provides a shipping link between the deep water of the Atlantic Ocean and ports 2400 miles inland on the American continent. This includes 1000 statute miles down the St. Lawrence River, 1350 miles over the Great Lakes, and 400 miles in connecting channels. In that distance there are nineteen locks comprising three sets of locks that lift ships from sea level to an elevation of 600 feet in Lake Superior. Figure 2.1 is a schematic cross-section of the GL/SLS System. Figure 2.2 shows the area covered by the system.

The capacity of any navigation system including the Great Lakes/St. Lawrence Seaway System is determined by the system's limiting or constraining element; the element which has the slowest processing time. In very general terms, the GL/SLS System can be thought of as a series of locks, connecting channels, and harbors. The complexity inherent in the three lock systems, the five connecting channels, and over forty harbors becomes even more significant when the numerous trade routes between the various harbors for inland traffic and for the ocean trade are also considered. Generally, for navigation systems equipped with locks, the traffic capacity, defined either in terms of annual tonnage or annual vessel transits, is constrained by the locks. Prior capacity studies of the GL/SLS System have indeed shown the locks to be the constraining element of this system. As the annual tonnage shipped on the GL/SLS navigation system continues to increase in the future, the demand for service at the locks will increase accordingly, and as the capacity limits of the system are approached, vessels will begin to experience long waiting times and long vessel queues at the locks. The resulting inability of the system to effectively service its customers would obviously be reflected by a decrease in the popularity and use of the system, with an adverse impact on the economic growth of the entire nineteen state region served by the system.

Any transportation system interested in serving its customers over the long term must plan to provide an expanded capacity when the need for such capacity is required by the system's users. For a simple system having one major constraining component, the removal of the constraint at that one point removes the system constraint. For a more complex system, such as the GL/SLS navigation system, the multiplicity of locks, connecting channels, and harbors presents a more challenging assignment to the planners addressing the removal of system

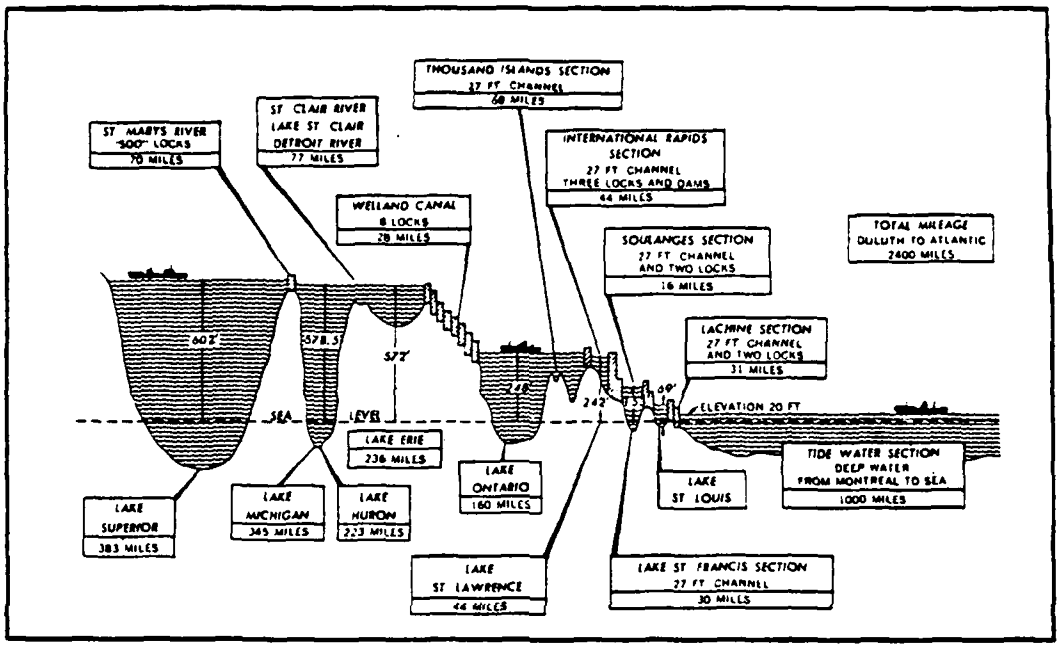


FIGURE 2.1 PROFILE OF GREAT LAKES-ST. LAWRENCE NAVIGATION SYSTEM

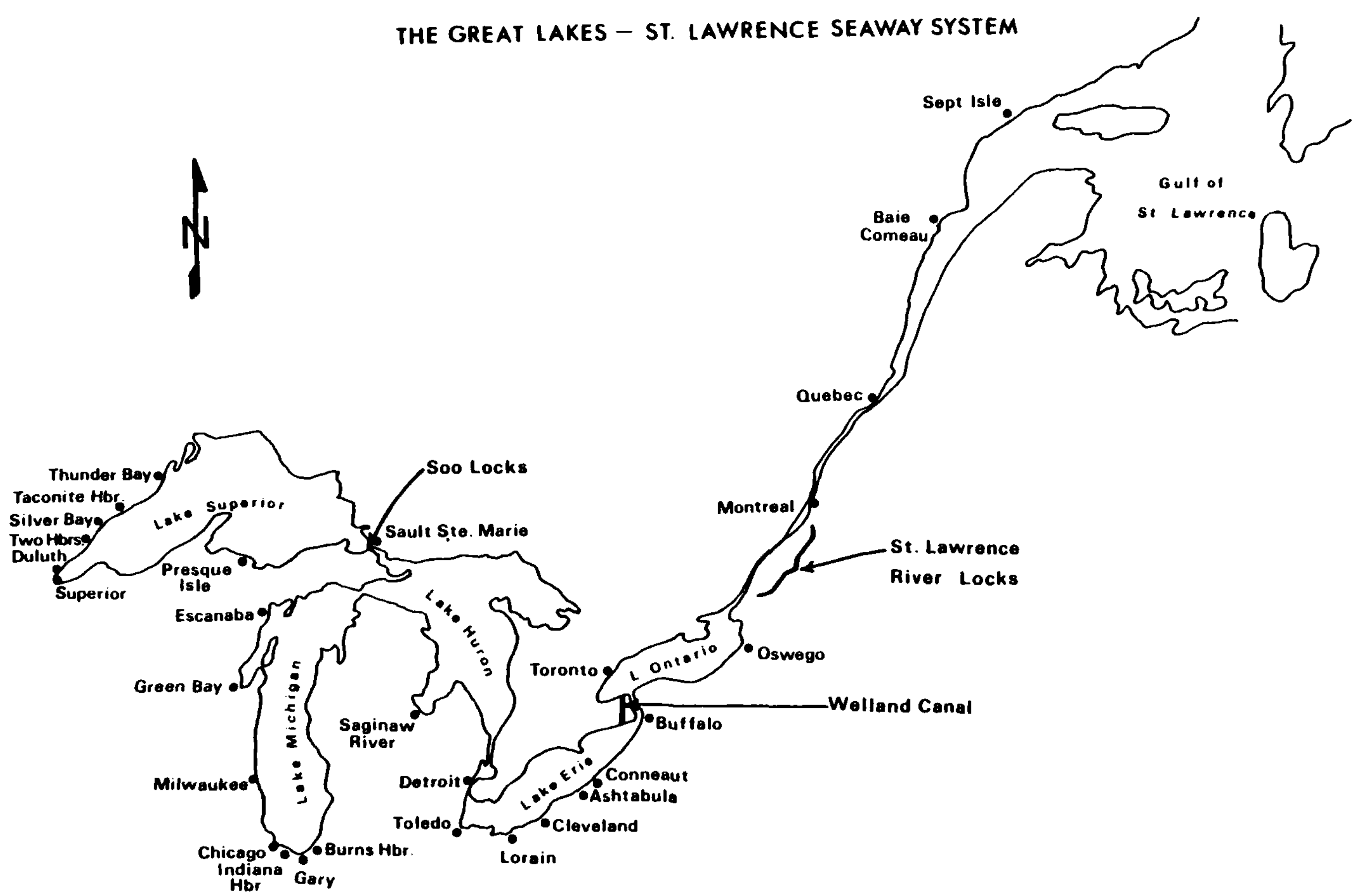


FIGURE 2.2 THE GREAT LAKES - ST. LAWRENCE SEAWAY SYSTEM

capacity constraints over the long term. An analysis of the entire system is required to ensure that removal of a constraint at one feature or location does not simply result in movement of the constraint to another feature or location with relatively little, if any, improvement in overall system capacity.

With such considerations in mind, the North Central Division of the U.S. Army Corps of Engineers initiated a study entitled, "Great Lakes/St. Lawrence Seaway Regional Transportation Studies", having as its primary objective the development of a sound documented working tool for use in analyzing GL/SLS regional transportation improvement alternatives. This report documents part of the work of Task 8 of this program, the objective of which is to perform a sensitivity and feasibility analysis of selected non-structural and structural alternatives for increasing lock capacity through the year 2050. This analysis was performed using the GL/SLS LOCK CAPACITY MODEL which, in simple terms, is a queuing model which analyzes steady state lock operations and vessel-lock interaction at the three lock systems.

The feasibility and sensitivity nature of this work is emphasized. The analysis of the non-structural alternatives selected by the Corps of Engineers for inclusion in this study should be interpreted not only in terms of the specific alternatives, but more broadly in terms of the capacity improvements potentially achievable through the appropriate reductions in lockage times at each of the lock systems. In similar fashion, the analysis of the structural alternatives selected by the Corps of Engineers for inclusion in this study should be interpreted more broadly in terms of the level of capacity improvement potentially achievable through enlarging particular lock characteristics, thereby allowing passage of longer and wider ships or deeper draft ships. Practically speaking, it may be considered unlikely that a lock system, for example, would be made deeper without also being made longer and wider as was the case for some of the structural alternatives investigated in this program. It is exactly this approach, however, that provides insight into the effect of system draft on system capacity. This feasibility and sensitivity approach must be born in mind throughout this report.

The model selected for use in this study was selected with the sensitivity and feasibility nature of the study in mind. The model focuses on the constraining lock in a series lock system and makes the assumption that system improvements are implemented at all of the locks in a system simultaneously. This implies that the initially constraining lock remains the constraining lock. This approach allows use of a model which is

relatively simple in structure and therefore relatively quick and inexpensive to run, allowing a large number of alternatives to be investigated for feasibility relatively quickly and at relatively low cost. It is cautioned, however, that this model is not suitable for use in investigating an individual lock system in great detail or for making final decisions on which non-structural or structural alternatives to implement. The model is extremely useful for evaluating system sensitivity and alternative feasibility, thereby defining those non-structural and structural alternatives which warrant further investigation. This is the purpose for which the model was developed and applied in this study and any attempt to read any greater significance or importance into the results obtained would be a serious mistake.

The following sections of this report include a brief description of the GL/SLS LOCK CAPACITY MODEL used in this study and its validation, descriptions of the results obtained with the model for both a low water datum and deeper water base case for the non-structural alternatives and for the structural alternatives, a summary of the costs associated with the alternatives, an analysis of all the results, and the conclusions and recommendations drawn from the study. The results of this work feed directly into the work associated with the determination of NED Benefits for the capacity expansion alternatives selected.

3. DESCRIPTION OF GL/SLS LOCK CAPACITY MODEL

3.1 Overall Description

In an overall view, the GL/SLS LOCK CAPACITY MODEL can be described as a queuing model which analyzes steady-state lock operations and vessel-lock interaction for the Soo, Welland, and St. Lawrence River Lock Systems. Its purpose is to provide a planning tool to aid in predicting if, or when in time, the Soo, Welland Canal, and St. Lawrence River Locks can be expected to reach a capacity condition, and to evaluate means by which the capacity of the lock systems may be increased. The capacity determinations are a function of:

- Cargo Traffic Projections
- Vessel Fleet Projections
- Vessel Operating Characteristics and Locking Times
- Lock Operating Characteristics
- Length of Navigation Season
- Available Operating Time (Weather Delays, Lock Malfunction Delays, Daylight-Only Navigation)
- Pleasure Craft and Non-Commercial Vessel Locking Requirements
- Winter Vessel and Lock Operating Procedures.

For a given set of the above listed data, the GL/SLS LOCK CAPACITY MODEL determines the following for fourteen separate time periods (ten months plus early and late April and early and late December):

- Cargo Transported by Commodity and Direction
- Vessel Operating Fleet
- Yearly Vessel Transit Demand by Vessel Class, Commodity, and Direction
- Daily Vessel Transit Demand by Vessel Class and Direction
- Lock Cycle Time by Direction (Mean and Standard Deviation)
- Average Vessel Waiting Time by Direction
- Average Vessel Queue Length by Direction
- Lock Utilization.

The model performs this analysis every two years from a base year to a prescribed final year. The lock cycle time, average vessel waiting time, average vessel queue length, and lock utilization are

output for each two year period, while the results of the entire analysis are output every decade. A schematic diagram of the Lock Capacity Model is shown in Figure 3.1.

The model also determines the year in which capacity is reached, based on 90% average lock utilization for the months of May through November. The entire output is printed for the capacity year and the model either ends the run for that lock or implements a non-structural or structural capacity expansion measure and continues the analysis until the final year is reached.

A typical output run for one year and one lock system is included in Appendix A as an example. This program was run on the EKS1 service of the Boeing Computer Network. A complete run consisting of all three lock systems analyzed from 1978 to 2050 submitted in batch costs approximately $33 at high priority. This does not include the costs of compilation and printing which are comparatively small compared to the run costs.

The GL/SLS LOCK CAPACITY MODEL is comprised of a series of individual modules. The purpose of each of these modules is as follows:

FLEET DETERMINATION MODULE determines the required vessel fleet mix to carry the projected cargo tonnage demand by commodity as a function of the existing fleet, vessel retirement or phase-out schedule, vessel building schedule, available operating time, specific trade routes, and vessel characteristics (carrying capacity, speed of advance, length, beam, ice transiting capability, vessel utilization factor, and required locking time) for the particular lock system. As output, the model generates a vessel fleet (number of ships) by vessel class (size) and commodity necessary to carry the projected annual cargo tonnage demand.

TRANSIT FORECAST MODULE converts the vessel fleet generated by the FLEET DETERMINATION MODULE and the annual cargo demand projections into a vessel transit forecast demand (vessel arrivals) by vessel class, direction, and commodity, that will arrive at that particular lock system on a daily basis as a function of vessel characteristics and vessel utilization (% of loaded backhauls).

SHIP DISPATCH MODULE is used only for the Soo Lock System where a decision must be made as to which of the locks a particular vessel will be assigned based on vessel-lock limitations and relative lock utilization and vessel waiting times. For the Soo Lock System, the objective is thus to establish a transit forecast

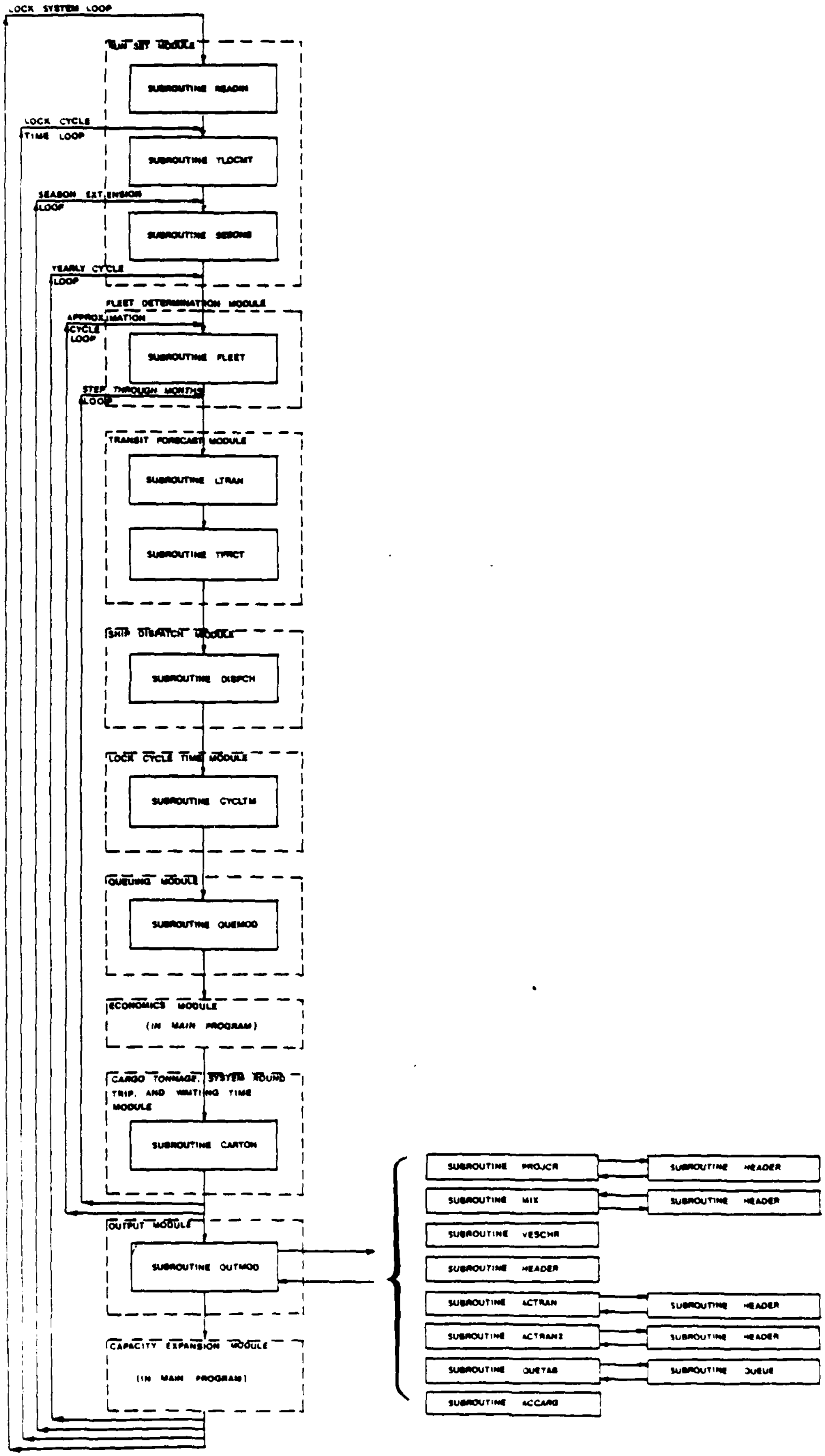


FIGURE 3.1 SCHEMATIC OF THE LOCK CAPACITY MODEL

of vessels by class, direction, and commodity that will arrive at each of the locks. This decision process is made on the basis of equating lock utilization within the constraints imposed by vessel-lock limitations.

LOCK CYCLE TIME MODULE calculates the mean lock cycle time as a function of the transit forecast of vessels by class, direction, lock turnback characteristics, and level of traffic.

LOCK QUEUING MODULE determines the average vessel waiting time, average vessel queue length, and lock utilization based on the vessel transit forecast, mean lock cycle time, available lock operating time, weather delays, lock malfunction delays, required pleasure craft and non-commercial lockages, and ice delays.

CAPACITY MODULE determines if lock capacity is reached and implements capacity expansion measures if they are desired.

In the following sections a list of basic assumptions for the GL/SLS LOCK CAPACITY MODEL and a brief description of each module are presented. A more detailed description of each individual module is presented in the documentation volume of this report.

3.2 List of Basic Assumptions

In developing the GL/SLS LOCK CAPACITY MODEL, the following basic assumptions were made:

Vessels

(1) All ships in the fleet are represented by specific ship classes.

(2) All ships will attempt to maintain their maximum capable speed at all times except where speed limits exist.

(3) A ship's maximum speed capability is determined by analyzing the ship's thrust capability versus its resistance characteristics in open water and ice.

(4) No accidents involving ships are assumed to occur in the system and no time delays due to accidents are considered.

(5) All ships are treated on an equal basis.

(6) All ships will operate only during daylight hours in areas where nighttime navigation is prohibited.

(7) All ships are assumed to carry a full cargo.

(8) All ships carry only one cargo at a time.

(9) Lakers are phased-out or retired from the fleet based on a 75 year useful life.

(10) When additional ships are needed because the cargo demand is greater than the fleet transporting capability, ships are built according to percentages which were determined from current building trends and are input as data into the model.

(11) When the cargo demand is less than the fleet transporting capacity, the smallest ships are deleted first.

Locks

(1) Each lock can be described as a single-server with a simple waiting line queue.

(2) Vessels are processed on a first come-first served basis.

(3) Lock service time distribution is characterized by its mean and standard deviation.

(4) Vessel arrival rate follows a Poisson distribution.

(5) Vessels are locked through in a manner which minimizes the lock's utilization (maximizes its capacity). If queues exist on both sides of the lock, the lock will alternate in processing upbound and downbound vessels. If a queue exists on one side of the lock and the time of arrival of a vessel at the other side of the lock is less than the turnback time of the lock, the lock will wait to process the arriving vessel. Otherwise, it will turn back to process the next vessel in the queue.

(6) Only one vessel at a time is processed by a lock.

(7) The capacity of each lock system is determined by the constraining lock and the distance between locks does not prohibit the Poisson distribution of vessel arrivals.

(8) At the Soo, vessels arriving are sorted by their use of the lock and form independent queues for each lock. In sorting vessels to each lock, vessels are assigned in a manner which minimizes the system's utilization (maximizes its capacity) within prescribed vessel-lock constraints. As queues start forming, vessels are dispatched to the waiting space provided at each lock in such a manner that no other vessel is blocked from entering an idle lock.

<u>Cargo</u>

(1) All cargo forecasts are considered to be the unconstrained maximum tonnage for each commodity that is expected to move through the GL/SLS System. All commodities are transported throughout the entire season. No additional tonnages are generated from extended season operation.

(2) Fifteen commodity tonnages are input. For use in the model these fifteen are grouped into six major commodity categories. These categories and their corresponding commodities are:

Grain:	wheat, soy beans, barley and rye, corn and oil seeds
Stone:	limestone
Iron Ore:	iron ore
Coal:	coal
Other Bulk:	raw materials, cement, petroleum products, minerals, and dry bulk
General Cargo:	general cargo and steel products

3.3 Description of Fleet Forecast Module

<u>Objective</u>

Determine the required vessel fleet mix for a given lock system needed to carry the projected cargo tonnage demand by

commodity as a function of the existing fleet, vessel retirement or phase-out schedule, vessel building schedule, available operating time, specific trade routes and vessel characteristics (carrying capacity, speed of advance, length, beam, ice transiting capability, vessel utilization factor, and required locking time).

Method of Approach

The method of approach used in the FLEET FORECAST MODULE is depicted in Figure 3.2 and consists of the following major steps:

(1) Determine the number of round trips each vessel class and commodity combination can make during the entire navigation season for a given set of input commodity trade route data, vessel characteristics and operating data (carrying capacity, vessel speed of advance, loading and unloading times, locking times, and extended season operations).

(2) Determine the remaining fleet commodity transporting capacity for the entire navigation season. Initially, older vessels are phased-out of the base year fleet in accordance with the vessel retirement or phase-out schedule and then the remaining fleet's transporting capacity by commodity is determined by:

$$RFCAP_i = \Sigma\ NSHIPS_{ij} \times NRTRIPS_{ij} \times CC_{ij} \qquad [3.1]$$

where

$RFCAP_i$ = Remaining fleet capacity for the ith commodity

$NSHIP_{ij}$ = number of vessels in remaining fleet of the ith vessel class transporting the ith commodity

$NRTRIPS_{ij}$ = number of round trips per year each vessel of the ith vessel class can make transporting the ith commodity

CC_{ij} = carrying capacity of each vessel of the ith vessel class for the jth commodity

Σ = summation over all vessel classes.

(3) Add (or delete) ships to (or from) the remaining fleet until the fleet commodity transporting capacity equals the annaul cargo tonnage demand. When the annual cargo tonnage demand is greater than the transport capacity of the remaining fleet,

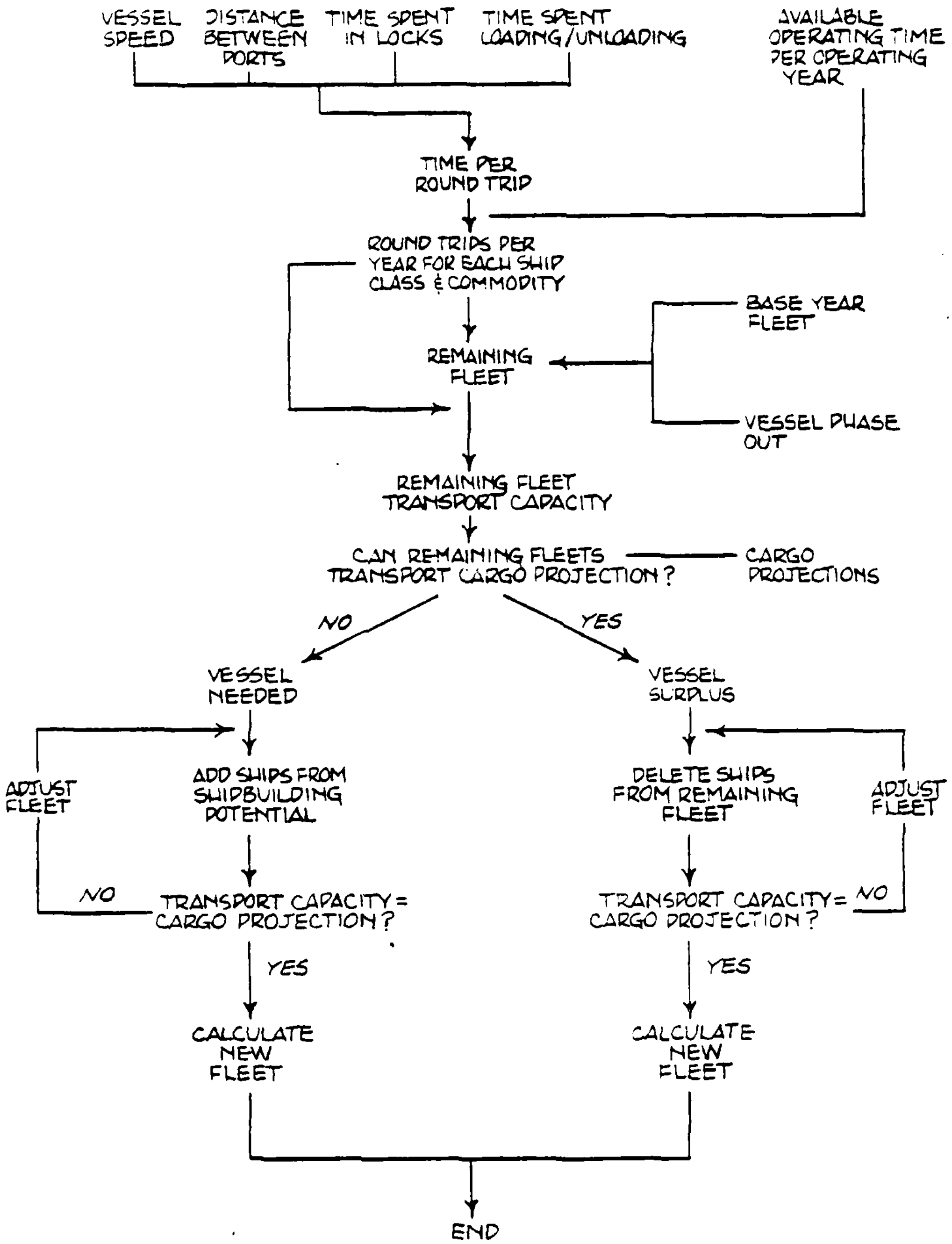


FIGURE 3.2. CONCEPT DIAGRAM OF FLEET FORECAST MODEL

ships are added to the fleet based on percentages established for each commodity and vessel class. These shipbuilding percentages are based on the current shipbuilding trends determined from historical records and from interviews with fleet operators. If the transport capacity of the remaining fleet is greater than the cargo tonnage demand, vessels are deleted from the fleet, with the smallest vessels being deleted first, until the transport capacity equals the cargo demand. Because vessels can be engaged in several commodity trades, this process of adding and deleting vessels is an iterative one which is repeated until the fleet transport capacity equals the cargo demand for every commodity.

Output

Required Vessel Fleet by Commodity and Vessel Class.

3.4 Description of Transit Forecast Module

Objective

Convert the vessel fleet mix generated by the FLEET DETERMINATION MODULE and the annual cargo demand projections into a vessel transit forecast demand (vessel arrivals), by vessel class, direction and commodity, that will arrive at the particular lock system on a daily basis as a function of vessel characteristics and vessel utilization (% of loaded backhauls) and bias traffic factor for the 14 time periods (10 months plus early and late April and early and late December).

Method of Approach

The method of approach used in the TRANSIT FORECAST MODULE is depicted in Figure 3.3 and consists of the following major steps:

(1) Calculate the loaded transits and cargo distribution for each time period for a given set of cargo tonnage demand and vessel characteristics and performance data.

(2) Calculate the ballast transit distribution for each time period based on vessel utilization factor ranging from 0.0 (one ballast transit for every loaded transit) to 1.0 (minimum number of ballast transits) and navigation season start-up and end bias traffic factors.

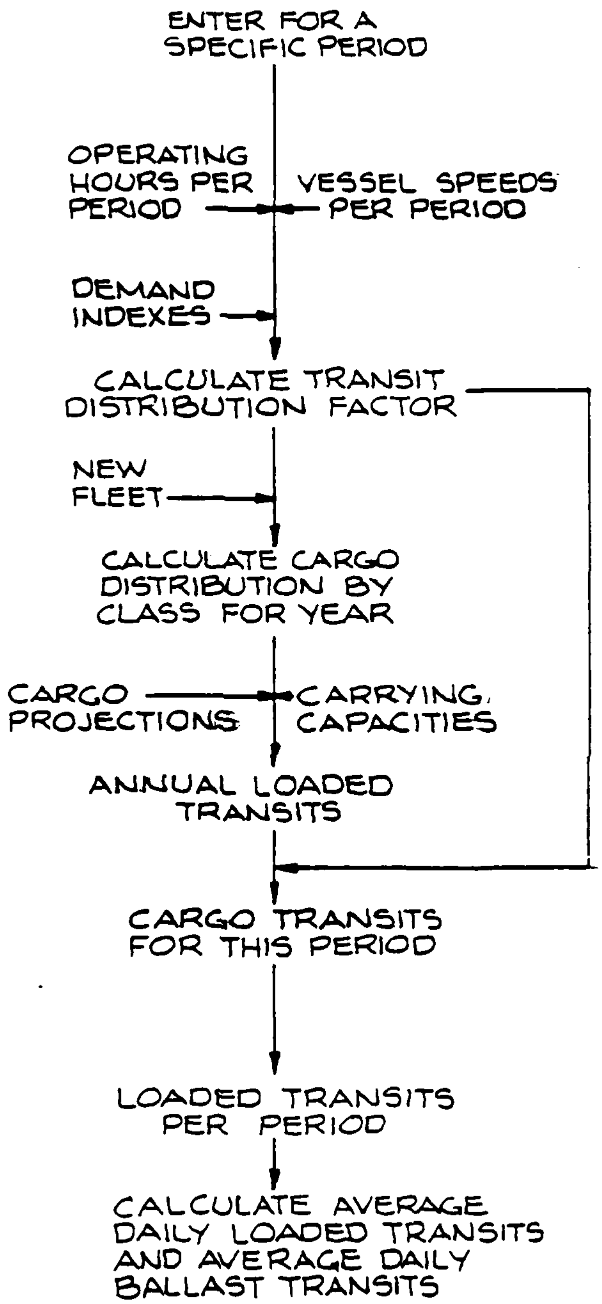


FIGURE 3.3 CONCEPT DIAGRAM FOR TRANSIT FORECAST MODEL

Output

Number of Daily Vessel Loaded and Ballast Transits (by vessel class, direction, and commodity) for the 14 time periods.

3.5 Description of Ship Dispatch Module

Objective

Distribute the daily number of vessel loaded transits (by vessel class, direction, and commodity) and ballast transits (by vessel class and direction) generated by the TRANSIT FORECAST MODULE to each of the Soo Locks.

Method of Approach

(1) Ships arriving at the locks are assigned by the lock master to a specific lock based on the physical limitations and availability of each lock. Based on physical limitations and to ensure maximum lock capacity (tonnage and number of daily transits), vessels are initially dispatched in the model depending upon the maximum ship size as follows:

(a) Maximum Vessel Class 10 (existing condition)

- Loaded Class 4 and ballasted Class 4, 5, 6, 7, and 8 vessels are assigned to the Sabin and Davis Locks
- Loaded Class 5, 6, and 7 vessels are assigned to the MacArthur Lock
- Loaded Class 8 and all Class 9 and 10 vessels assigned to the Poe Lock.

(b) Maximum Vessel Class 11 (Davis Lock replaced with a 1350 x 115 foot lock)

- Loaded Class 4 and ballasted Class 4, 5, 6, 7 and 8 vessels are assigned to the Sabin Lock
- Loaded Class 5, 6, and 7 vessels are assigned to the MacArthur Lock
- Loaded Class 8 and all Class 9 and 10 vessels are assigned to the Poe Lock
- All Class 11 vessels are assigned to the new Davis Lock.

(c) Maximum Vessel Class 12 (Sabin and Davis Locks are replaced by a 1460 x 145 foot lock)

- All Class 4, 5, 6, and 7 vessels are assigned to the MacArthur Lock
- All Class 8, 9, and 10 vessels are assigned to the Poe Lock
- All Class 11 and 12 vessels are assigned to the new Sabin-Davis Lock.

(2) Lock utilizations for each lock are calculated based on the initial assignments. Within the physical size constraints of the locks, vessels are reassigned in a manner that will minimize lock utilization (maximize capacity).

Output

Daily Number of Vessels and Loaded and Ballasted Transits (by vessel class, commodity, and direction) at the Soo Locks for 14 time periods.

3.6 Description of Lock Cycle Time Module

Objective

Calculate the mean upbound and downbound lock cycle times and their variances as a function of the transit forecast of vessels by class and direction, lock turnback characteristics and level of traffic for each of the 14 time periods.

Method of Approach

The method of approach used in the LOCK CYCLE TIME MODULE consists of the following major steps:

(1) Calculate the one-way mean locking time and its variance for upbound and downbound vessel transit forecast. Expressed mathematically:

$$t_{l_{up}} = \sum_{j=1} f_{j_{up}} \times t_{l_{j,up}}$$

$$t_{l_{down}} = \sum_{j=1} f_{j_{down}} \times t_{l_{j,down}}$$

$$\sigma_{up} = \sum_j f_{j_{up}} \times \sigma^2_{j_{up}} + \sum_j f_{j_{up}} (t_{l_{j,up}} - t_{l_{up}})^2$$

$$\sigma_{down} = \sum_j f_{j_{down}} \times \sigma^2_{j_{down}} + \sum_j f_{j_{down}} (t_{l_{j,down}} - t_{l_{down}})^2$$

where

$t_{l_{up}}, t_{l_{down}}$ = upbound and downbound one-way mean locking time

$f_{j_{up}}, f_{j_{down}}$ = upbound and downbound fractions of total transits of class j vessel transits

$t_{l_{jup}}, t_{l_{jdown}}$ = upbound and downbound one-way locking times of class j vessels

$\sigma_{up}, \sigma_{down}$ = upbound and downbound one-way mean locking time variance

$\sigma_{j_{up}}, \sigma_{j_{down}}$ = upbound and downbound one-way locking time variance of class j vessels

$\sum_j$ = summation over all vessel classes.

(2) Calculate the mean lock cycle time and its variance for upbound and downbound vessel transit forecast. If ships are waiting on both sides of the lock, the mean lock cycle time is simply the sum of the mean locking time for downbound ships and the mean locking time for upbound ships, while if the traffic is one-way, i.e., either entirely upbound or entirely downbound, the mean cycle time is the sum of the one-way mean locking time plus the time for the lock to turn back and get ready to process the next ship. For the general case when vessels are not necessarily waiting to be serviced, the mean lock cycle time and its variance can be expressed by the following equations which can be solved simultaneously.

$$t_{c_{up}} = t_{l_{up}} + (1-\rho_{down})\ t_b + \rho_{down}\ t_{l_{down}}$$

$$t_{c_{down}} = t_{l_{down}} + (1-\rho_{up})\ t_b + \rho_{up}\ t_{l_{up}}$$

$$\rho_{up} = \lambda_{up} \times t_{c_{up}}$$

$$\rho_{down} = \lambda_{down} \times t_{c_{down}}$$

$$\sigma^2_{c_{up}} = \sigma^2_{up} + (1-\rho_{down})^2 + \rho^2_{down}\ \sigma^2_{down}$$

$$\sigma^2_{c_{down}} = \sigma^2_{down} + (1-\rho_{up})^2 + \rho^2_{up}\ \rho^2_{up}$$

where

$t_{c_{up}}, t_{c_{down}}$ = upbound and downbound mean lock cycle time

$\sigma_{c_{up}}, \sigma_{c_{down}}$ = upbound and downbound variance of the mean lock cycle time

$t_{l_{up}}, t_{l_{down}}$ = upbound and downbound one-way mean locking time

t_b = turnback time

ρ_{up} = probability of the lock serving an upbound vessel

ρ_{down} = probability of the lock serving a downbound vessel

$\sigma_{up}, \sigma_{down}$ = upbound and downbound one-way locking time variance.

$\lambda_{up}, \lambda_{down}$ = upbound and downbound vessel arrival rate

Output

Mean Upbound and Downbound Lock Cycle Times and their variances for the 14 time periods.

3.7 Description of Lock Queue Module

Objective

Determine average vessel waiting time, average vessel queue length, and monthly lock utilization based on the vessel transit forecast, mean lock cycle time, available lock operating time, weather delays, lock malfunction delays, required pleasure craft and non-commercial lockages and ice delays.

Method of Approach

The LOCK QUEUE MODULE can be described as a single server, simple waiting line model, characterized as M/G/1. The solution

of the M/G/1 model, known as the Pollaczek-Khentchine Formula, is based on the following assumptions:

- Poisson arrival; that is, exponential interarrival time
- Arbitrary service time with its known mean and standard deviation.

Under these conditions, the average queue length (L_q) and the queue waiting time (W_q) can be determined from the following equations:

$$L_q = \frac{\lambda^2 \sigma^2 + \rho^2}{2(1 - \rho)}$$

$$W_q = \frac{L_q}{\lambda} \quad .$$

where

λ = vessel interarrival rate (number of ships arriving per unit time)

σ = *variance of mean lock cycle time*

ρ = lock utilization ($= \lambda t_c$)

t_c = mean lock cycle time.

Using the appropriate data, these equations are used to determine the average queue length and average waiting time of ships for both upbound and downbound traffic at the lock for each of the 14 time periods.

In addition, as a first approximation, the model estimates the round trip time (transit + waiting) for the Welland Canal and St. Lawrence River systems. This total round trip time consists of the sum of the locking times, queuing waiting times, and transit times in reaches. Expressed mathematically:

$$\text{Total Round Trip Time} = (t_{c_{\text{up}}} + t_{c_{\text{down}}})/2 + W_{q_{\text{up}}} + W_{q_{\text{down}}} + (t'_{c_{\text{up}}} + t'_{c_{\text{down}}})/2 + (W'_{q_{\text{up}}} + W'_{q_{\text{down}}}) \times N + TT.$$

where

$t_{c_{up}}$, $t_{c_{down}}$ = upbound and downbound mean lock cycle time at the constraining lock

$t'_{c_{up}}$, $t'_{c_{down}}$ = upbound and downbound mean lock cycle time at the remaining locks

$W_{q_{up}}$, $W_{q_{down}}$ = upbound and downbound average queue waiting time at the constraining lock

$W'_{q_{up}}$, $W'_{q_{down}}$ = upbound and downbound average queue waiting time at the remaining locks

TT = round trip transit time in the reaches

N = number of remaining locks.

Output

Average Vessel Waiting Time, Average Vessel Queue Length, and Lock Utilization for both upbound and downbound for 14 time periods.

3.8 Description of the Capacity Expansion Module

Objective

Determine if capacity of a lock has been reached and if so, implement a capacity expansion measure, if desired.

Method of Approach

The method of approach used in the Capacity Expansion Module consists of the following major steps:

(1) Determine if capacity has been reached by calculating the average lock utilization at the constraining lock for the months of May through November. If this average lock utilization is greater than 90%, capacity is reached.

(2) If capacity is reached determine if a capacity expansion measure is to be implemented and if so, determine what measure is to be implemented. This information is provided as input data. Capacity may be expanded by reducing locking times, deepening ship draft, or building new locks. Any one or any combination of these alternatives may be used.

(3) Implement the chosen capacity expansion measure. If no measure is to be implemented, the analysis will stop here and move to the next lock system. If capacity is to be expanded, the required new data will be read and the calculations needed to implement these changes will be made. Simulation will resume with the next two year period following the capacity year.

Output

The year capacity is reached in each lock system and the capacity expansion information.

4. VALIDATION OF GL/SLS LOCK CAPACITY MODEL

4.1 Introduction

With any computer model which is supposed to represent a real-world phenomenon, the model's results or predictions are only as good as the basic input data and the basic rules and assumptions used in its development. The test of how realistically the computer model represents the actual conditions at each of the lock systems is shown through its validation, which is a direct measure of its credibility. Based on the validation presented in this section, we believe that the model agrees well with the real-world conditions for the validation year of 1976 and, as a result, the model predictions for future years can be viewed with a degree of confidence within the constraints imposed by the basic rules, assumptions, and input data.

A validation year of 1976 was chosen because locking information is well documented for that year. It is felt that 1976 was a good, typical year in which there were no extraordinary factors which would have affected cargo movements through the GL/SLS system.

4.2 Soo Lock System

4.2.1 Brief Description of the Soo Locks

The Soo Locks are located at Sault Ste. Marie, Michigan. Before the Navigation Season Extension Program started, the Soo Locks operated for approximately nine months of each year from early April through late December. During the Season Extension Demonstration Program, the Soo Locks were kept open into February for the first three years (1972 to 1974) and for 12 months for the remaining years of 1975 through 1979 [1]. For the 1980-81 season, operations were halted on 31 December 1980.

The Soo lock system consists of four parallel locks, the MacArthur, Poe, Davis, and Sabin locks, as shown in Figure 4.1. Each lock has its own pier that can accommodate two or three ships in each queue. In addition to the four United States locks, an older lock is located on the Canadian side of the St. Marys River. This lock, however, is small and shallow, and is used primarily by passenger vessels, pleasure craft, and other small ships carrying only a very small amount of cargo. Because of this, the Canadian lock has been excluded from the analysis of the Soo Lock capacity.

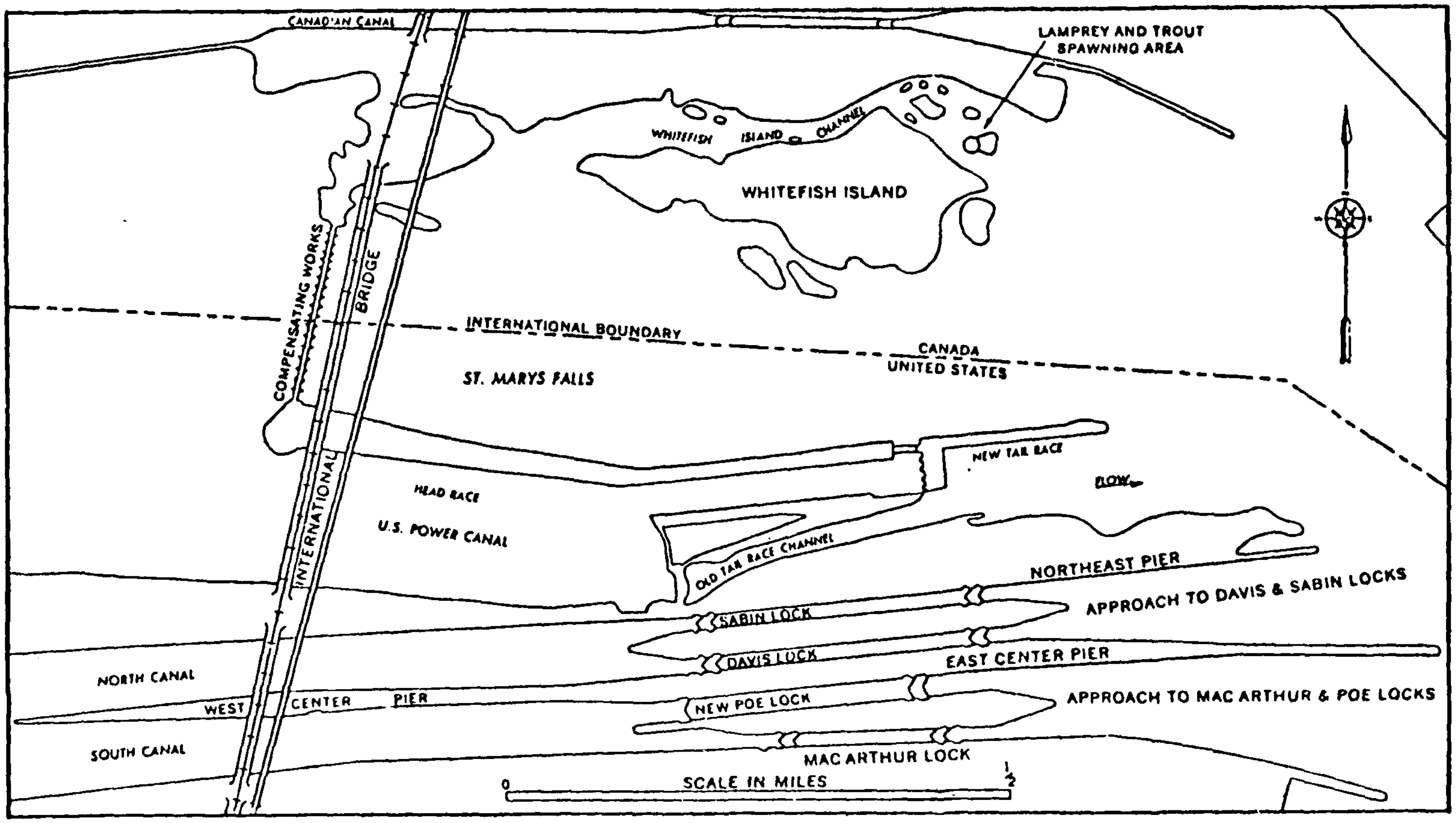


FIGURE 4.1 SOO LOCK SYSTEM

Currently, the MacArthur Lock handles most of the downbound loaded ships with an overall length of up to 730 ft, but can accommodate ships up to 767 ft in length with special locking procedures. The Poe Lock can process ships up to 1015 ft in length with a beam of 105 ft and currently handles mostly "1000 footers" and vessels that the MacArthur Lock cannot service. The Sabin and Davis Locks are identical in size and handle most of the ballasted upbound ships having a beam of up to 75 ft and length of up to 836 ft. Because of the shallow depth of both the Sabin and Davis Locks, the number of vessels using these locks has decreased as vessels have either been retired or phased-out of the fleets which use the Soo Locks. As a result, only the Sabin or Davis Lock is usually operated unless there is sufficient demand to warrant the operation of both locks. Table 4.1 shows the dimensions of the Soo Locks and ship size restrictions.

4.2.2 Model Validation at the Soo Locks

In validating the GL/SLS LOCK CAPACITY MODEL for the Soo, the criterion used for the validation was to compare model predictions based on transporting the actual tonnage with actual Soo conditions in 1976 for:

(1) Number of average daily transits by month,

(2) Distribution of vessel arrivals by vessel class (lockage mix),

(3) Ratio of loaded vessel transits to total vessel transits.

In addition, if the data had been readily available, we would have also included comparisons of actual versus predicted vessel waiting times and vessel queue lengths experienced at the Soo. Of the three items listed, the first two were considered to be of particular importance because they directly establish the lock capacity in terms of transits per day and tonnage transported.

The validation computer run for 1976 was made for the current level of ship utilization of 80% (ship utilization of 1.0 indicates that the minimum possible number of ballast transits are assigned, whereas ship utilization of 0.0 indicates one ballast transit for every loaded transit). From this run, agreement was determined to be quite good between the model predictions and the actual Soo conditions for the number of

TABLE 4.1 SOO LOCKS DIMENSIONS [2, 3]

PRINCIPAL FEATURES	MACARTHUR	SABIN	DAVIS	POE	CANADIAN
Lock width, ft	80	80	80	110	59
Maximum ship beam, ft	75	75	75	105	-
Length between mitre sills, ft	800	1350	1350	1200	900
Maximum ship length, ft	730*	836	826	1015	-
Depth on upper mitre sill, ft	31	24.3	24.3	32	16.8
Depth on lower mitre sill, ft	31	23.1	23.1	32	16.8
Lift, ft	22	22	22	22	22

* 767 foot ships permitted with special handling.

average daily transits and the distribution of vessel arrivals by vessel class. A summary of each of these comparisons is presented in Figures 4.2 and 4.3. A comparison of the ratio of loaded to total vessel transits between the model and actual Soo conditions could not be made since the data is not readily available. We would, however, expect the model to predict a lower ratio of loaded to total transits than actual conditions, similar to that found for the St. Lawrence and Welland. However, we would expect the difference to be less for the Soo, since vessels transiting the Soo tend to operate at closer to their carrying capacity than the typical vessel at the Welland or St. Lawrence.

4.3 Welland Canal Lock System

4.3.1 Brief Description of the Welland Canal Locks

The Welland Canal, shown in Figure 4.4, is located approximately 20 miles west of the Niagara River and connects Lake Erie to Lake Ontario. The canal contains eight locks over a distance of 27 miles that provide a lift of 326 feet between Lake Ontario and Lake Erie. Of the eight locks, Locks 1 through 7 are lift locks, while Lock 8 is primarily a guard lock. Locks 1, 2, 3, and 8 are single locks that handle both upbound and downbound traffic. Locks 4, 5, and 6, called "flights" because they resemble stairs, lift ships a total of 135 feet over the Niagara Escarpment. These locks are twinned permitting parallel traffic, but each set of three locks is essentially a single lock system because once a ship enters it must be locked all the way through the three before the next ship is serviced. Lock 7 is considered to be the most constraining lock in the system because of its longer locking time and because of its somewhat curving channel located only about 1800 feet away from the flights. Table 4.2 shows the lock dimensions and the maximum ship size.

4.3.2 Model Validation at the Welland Locks

In validating the GL/SLS LOCK CAPACITY MODEL for the Welland, the criterion used for validation was to compare model predictions based on transporting of the actual tonnage with actual Welland conditions in 1976 for:

(1) Number of average daily transits by month,

(2) Distribution of vessel arrivals by vessel class (lockage mix), and

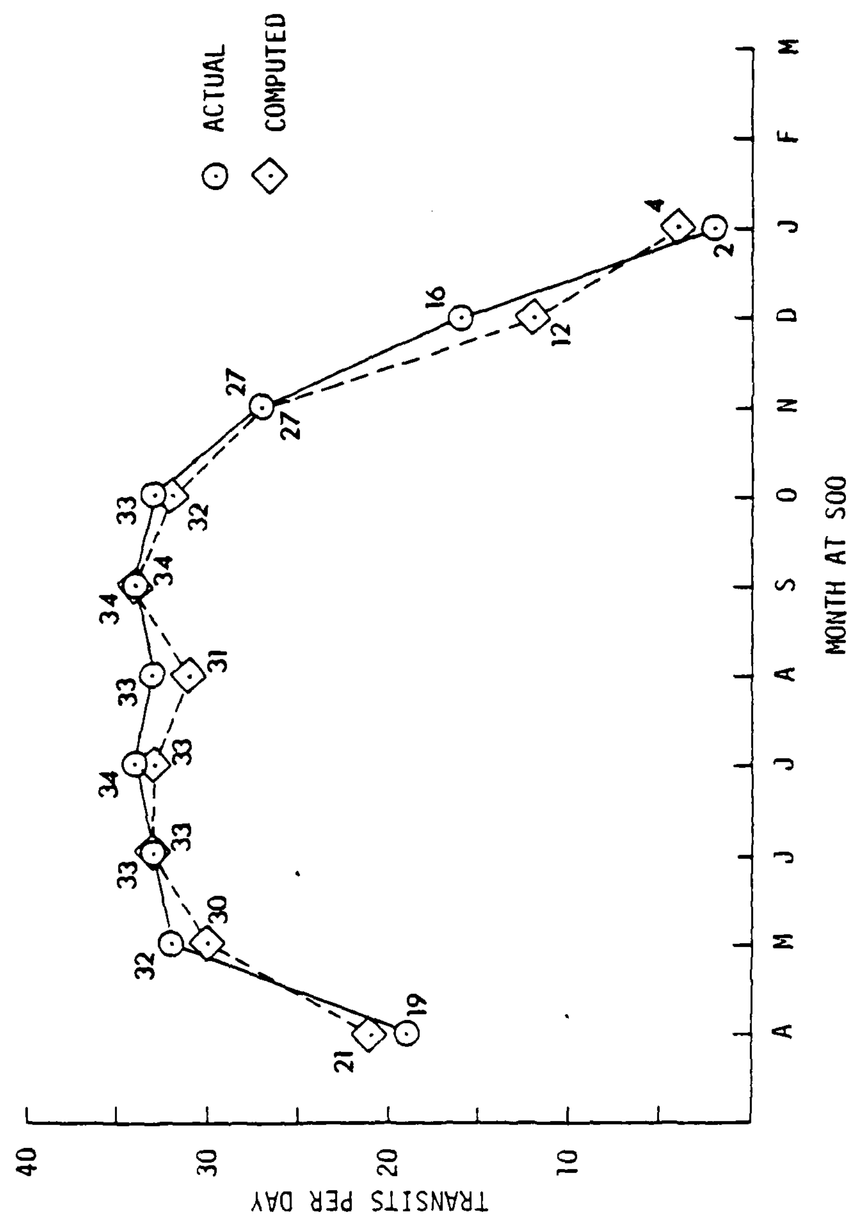


FIGURE 4.2 1976 DAILY TRANSITS BY MONTH AT THE SOO LOCKS

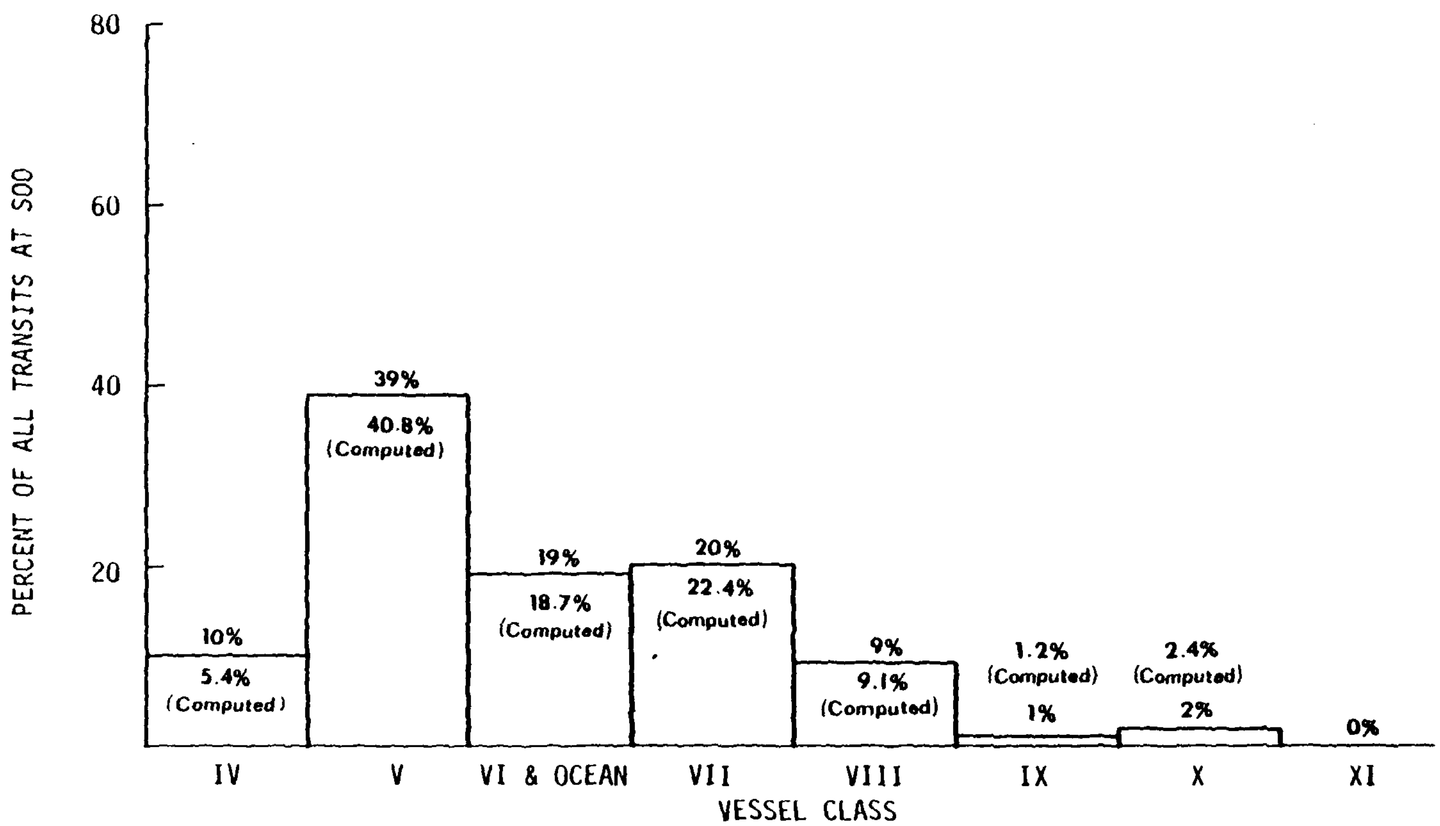


FIGURE 4.3 PERCENT VESSEL TRANSITS BY VESSEL CLASS AT THE SOO LOCKS FOR JUNE 1976

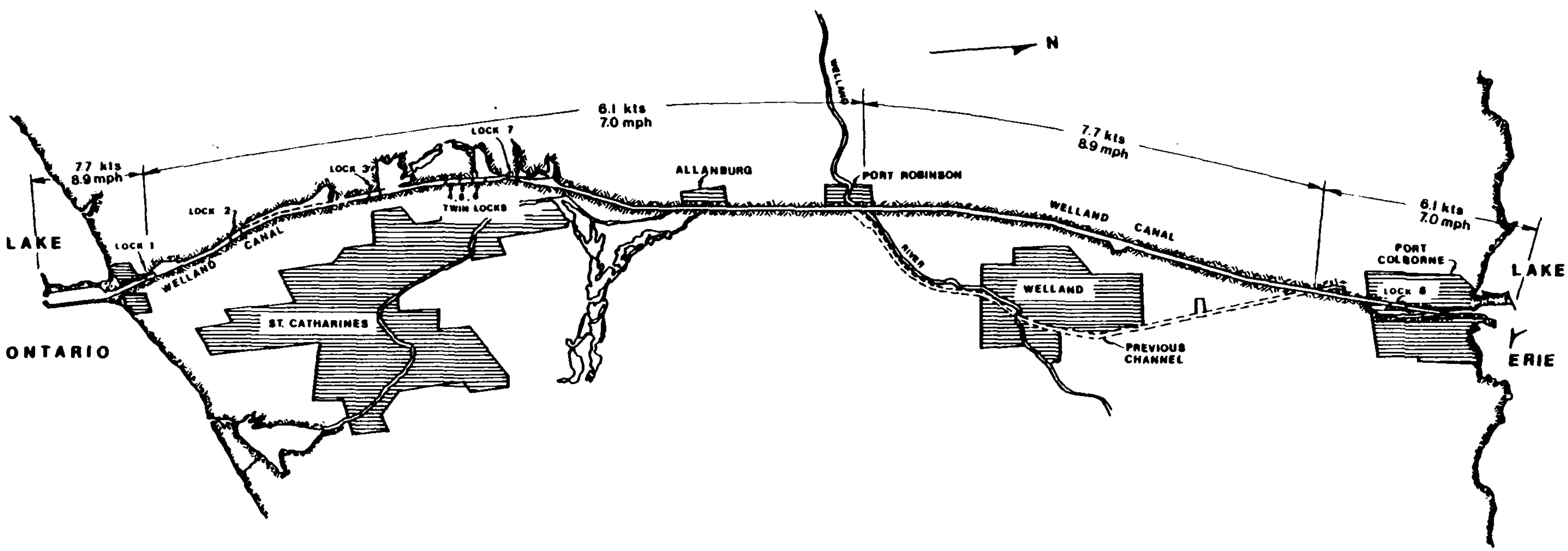


FIGURE 4.4 THE WELLAND CANAL AND LOCKS

TABLE 4.2 WELLAND CANAL LOCKS DIMENSIONS [4]

LOCK	LENGTH (ft)	WIDTH (ft)	DEPTH OVER SILLS (ft)	LIFT (ft)
All Locks	766[1]	80	30	46.5[3]
Maximum Ship Size	730	76	25.5 (draft)[4]	
Lock 1	865[2]			
Lock 2-7	859[2]			
Guard Lock 8	1380[2]			

Notes:

1. Breast wall to gate fender.
2. Center to center of inner gate pintles.
3. Lift for Locks 1 to 7; variable lift for Lock 8, normally less than 3 ft.
4. Draft at low water datum.

(3) Ratio of loaded vessel transits to total vessel transits.

In addition, if the data had been readily available, we would have also included comparisons of actual versus predicted vessel waiting times and vessel queue lengths experienced on the Welland. Of the three items listed, the first two were considered to be of particular importance because they directly establish the lock capacity in terms of transits per day and tonnage transported.

The validation computer run for 1976 was made with a ship utilization of 70% (ship utilization of 1.0 indicates that the minimum possible number of ballast transits are assigned, whereas ship utilization of 0.0 indicates one ballast transit for every loaded transit). From this run, agreement was determined to be quite good between model predictions and the actual Welland conditions for the number of average daily transits and the distribution of vessel arrivals by vessel class. A summary of each of these comparisons is presented in Figures 4.5 and 4.6. Comparing the ratio of loaded to total vessel transits, the agreement, as shown below, is not quite as good.

RATIO OF LOADED TO TOTAL VESSEL TRANSITS

	ACTUAL	COMPUTED
Upbound	63%	49%
Downbound	90%	84%

This discrepancy between the model predictions and actual conditions is due, we believe, primarily to the fact that all ship transits in the model are either carrying a full load of cargo or are in ballast, whereas in reality many vessels transiting the Welland are transporting less than a full load; that is, they are operating at 50% to 75% of full load. While this agreement is not as good as we would like for the validation year (1976), we resisted decreasing the carrying capacity of each class of vessel, which would have increased the predicted ratio. Looking ahead towards the capacity conditions at the Welland, vessels will most likely be operated at closer to their carrying capacity conditions than they currently are.

4.4 St. Lawrence River Lock System

4.4.1 Brief Description of St. Lawrence River Locks

The St. Lawrence River connects Lake Ontario to the Gulf of St. Lawrence. The St. Lawrence System, shown in Figure 4.7,

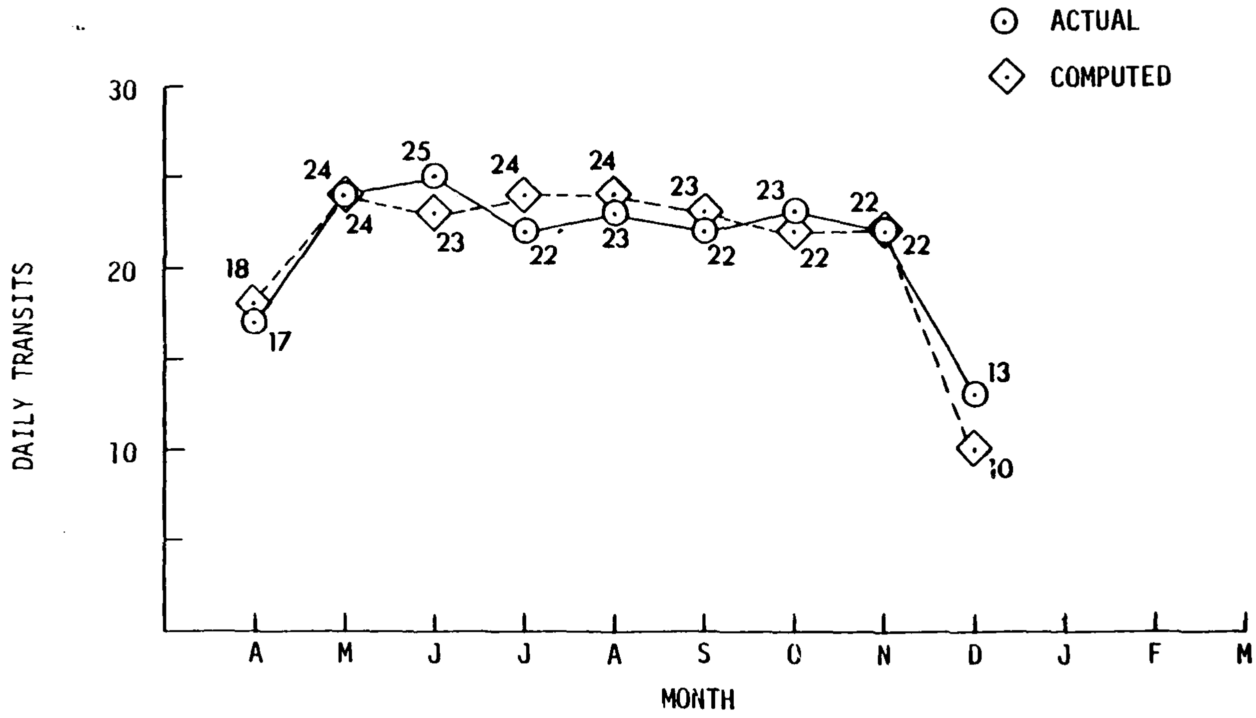


FIGURE 4.5 1976 DAILY TRANSITS BY MONTH AT WELLAND CANAL

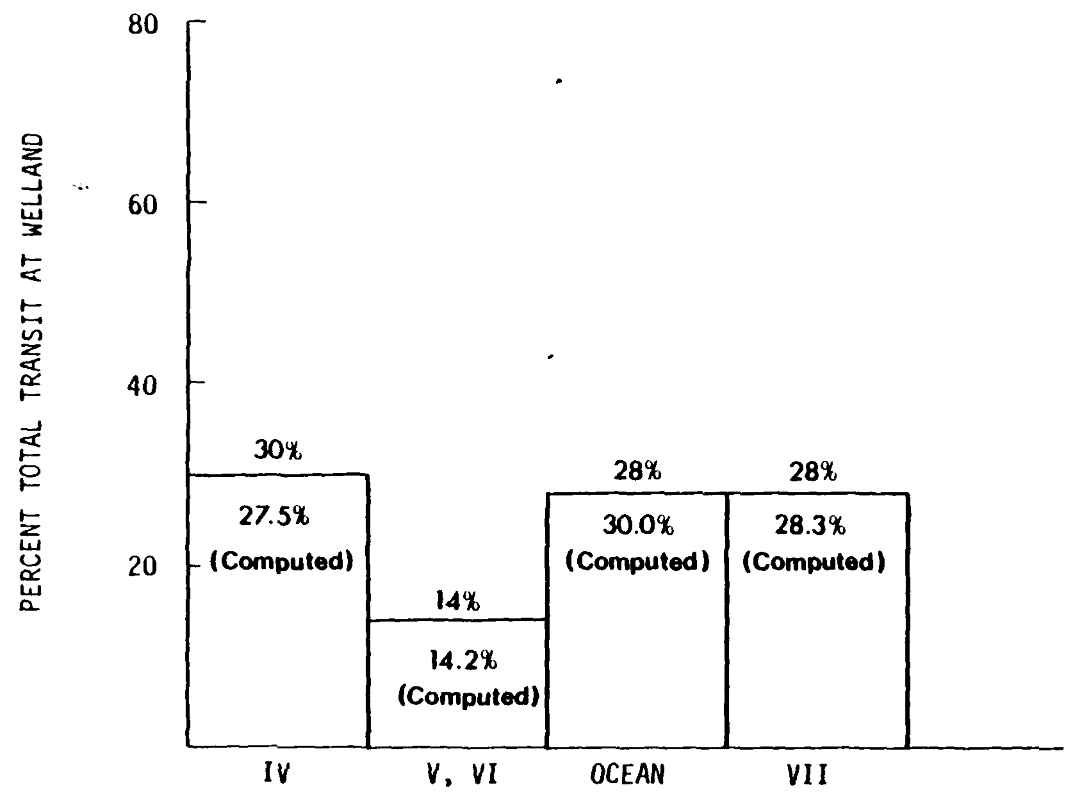


FIGURE 4.6 PERCENT VESSEL TRANSITS BY VESSEL CLASS AT WELLAND CANAL FOR 1976

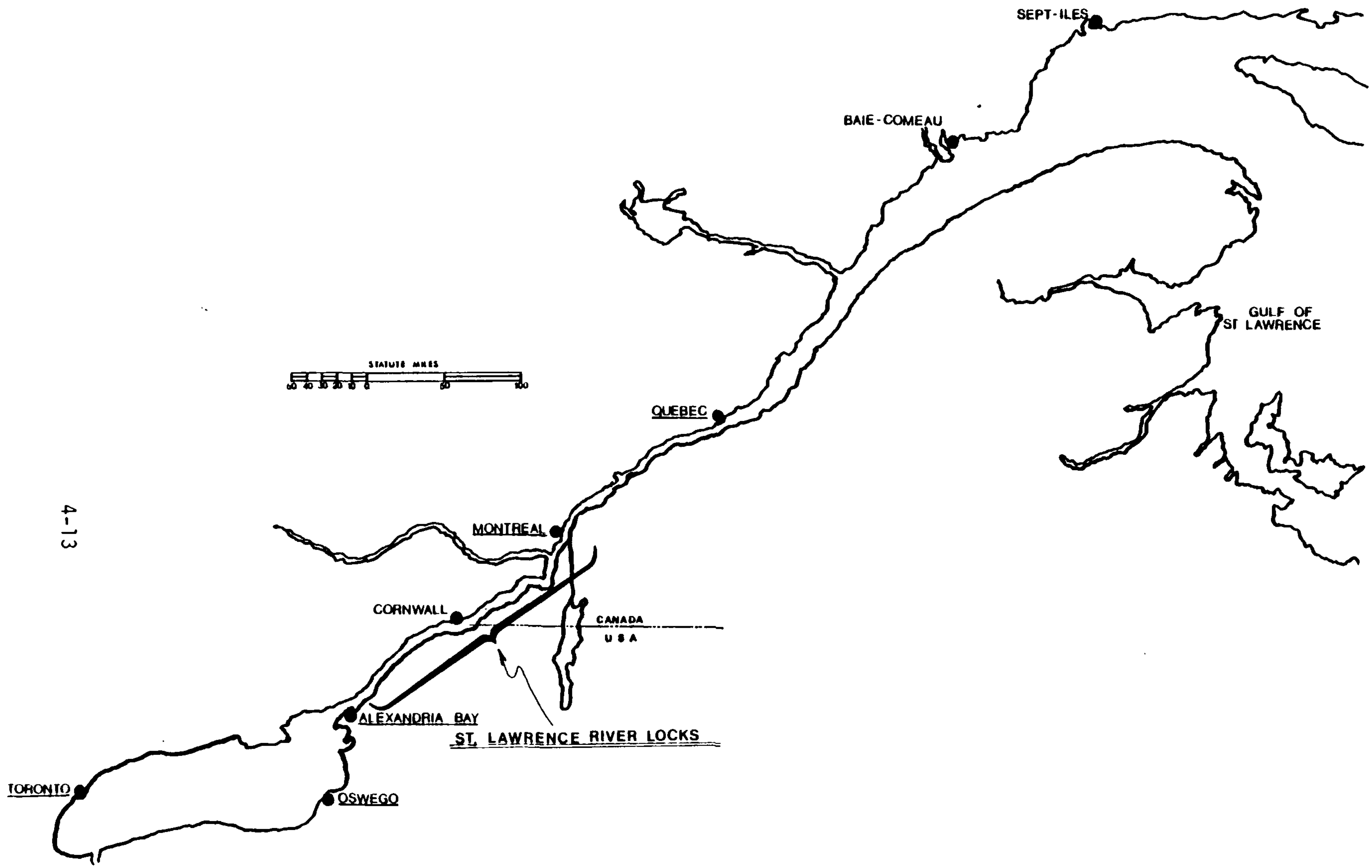


FIGURE 4.7 THE ST. LAWRENCE RIVER AND LOCKS

extends approximately 190 miles from St. Lambert Lock at Montreal to Kingston, Ontario, on Lake Ontario.

The System was created by excavation of channels to a depth of 27 feet, permitting the transit of vessels drawing 25.5 feet with water levels at low water datum, and the construction of seven single locks to by-pass certain rapid sections of the river. Of the seven locks, two are operated by the United States; the Snell and Eisenhower Locks located near Massena, New York. Five locks are operated by Canada; the St. Lambert and Cote Ste. Catherine Locks located near Montreal, the Upper and Lower Beauharnois Locks located in the Beauharnois Power Canal, and the Iroquois Lock located at Iroquois, Ontario.

The major constraint to traffic is generally considered to be the Beauharnois Locks. These locks are relatively close together and provide no waiting area for vessels between the locks. In addition, during the peak summer months, the Beauharnois Locks experience more transits by pleasure craft than any other locks due to travel to and from Montreal.

All seven locks are similar in size and all are capable of locking a ship that has a length of 730 feet and a beam of 76 feet. Table 4.3 shows the detailed lock dimensions and ship capacity.

4.4.2 Model Validation at the St. Lawrence River Locks

In validating the GL/SLS LOCK CAPACITY MODEL for the St. Lawrence, the criterion used for validation was to compare model predictions based on transporting the actual tonnage with actual St. Lawrence conditions in 1976 for:

(1) Number of average daily transits by month,

(2) Distribution of vessel arrivals by vessel class (lockage mix),

(3) Ratio of loaded vessel transits to total vessel transits.

In addition, if the data had been readily available, we would have also included comparisons of actual versus predicted vessel waiting times and vessel queue lengths experienced at the St. Lawrence. Of the three items listed, the first two were considered to be of particular importance because they directly establish the lock capacity in terms of transits per day and tonnage transported.

TABLE 4.3 ST. LAWRENCE RIVER LOCK DIMENSIONS [5]

Length, breast wall to gate fender	766 feet
Width	80 feet
Depth over sills	30 feet

Ships may not exceed 730 feet in overall length or 76 feet in maximum beam

Locks:

St. Lambert	13 to 22 feet
Cote Ste. Catherine	28 to 37 feet
Lower Beauharnois	38 to 42 feet
Upper Beauharnois	36 to 40 feet
Snell	45 to 49 feet
Eisenhower	38 to 42 feet
Iroquois	0.5 to 6 feet

The validation computer run for 1976 was made with a ship utilization of 70% (ship utilization of 1.0 indicates that the maximum possible number of ballast transits are assigned, whereas ship utilization of 0.0 indicates one ballast transit for every loaded transit). From this run, agreement was determined to be quite good between the model predictions and the actual St. Lawrence conditions for the number of average daily transits and the distribution of vessel arrivals by vessel class. A summary of each of these comparisons is presented in Figures 4.8 and 4.9. Comparing the ratio of loaded to total vessel transits, the agreement is not quite as good.

RATIO OF LOADED TO TOTAL VESSEL TRANSITS

	ACTUAL	COMPUTED
Upbound	82%	59%
Downbound	82%	70%

The discrepancy between the model predictions and actual conditions is due, we believe, primarily to the fact that all ship transits in the model are either carrying a full load of cargo or are in ballast, whereas in reality many vessels transiting the St. Lawrence are transporting less than a full load; that is, they are operating at 50% to 75% of full load. While this agreement is not as good as we would like for the validation year of 1976, we resisted decreasing the carrying capacity of each class of vessel, which would have increased the predicted ratio. Looking ahead towards the capacity condition at the St. Lawrence, vessels will most likely be operated at closer to their carrying capacity conditions than they currently are.

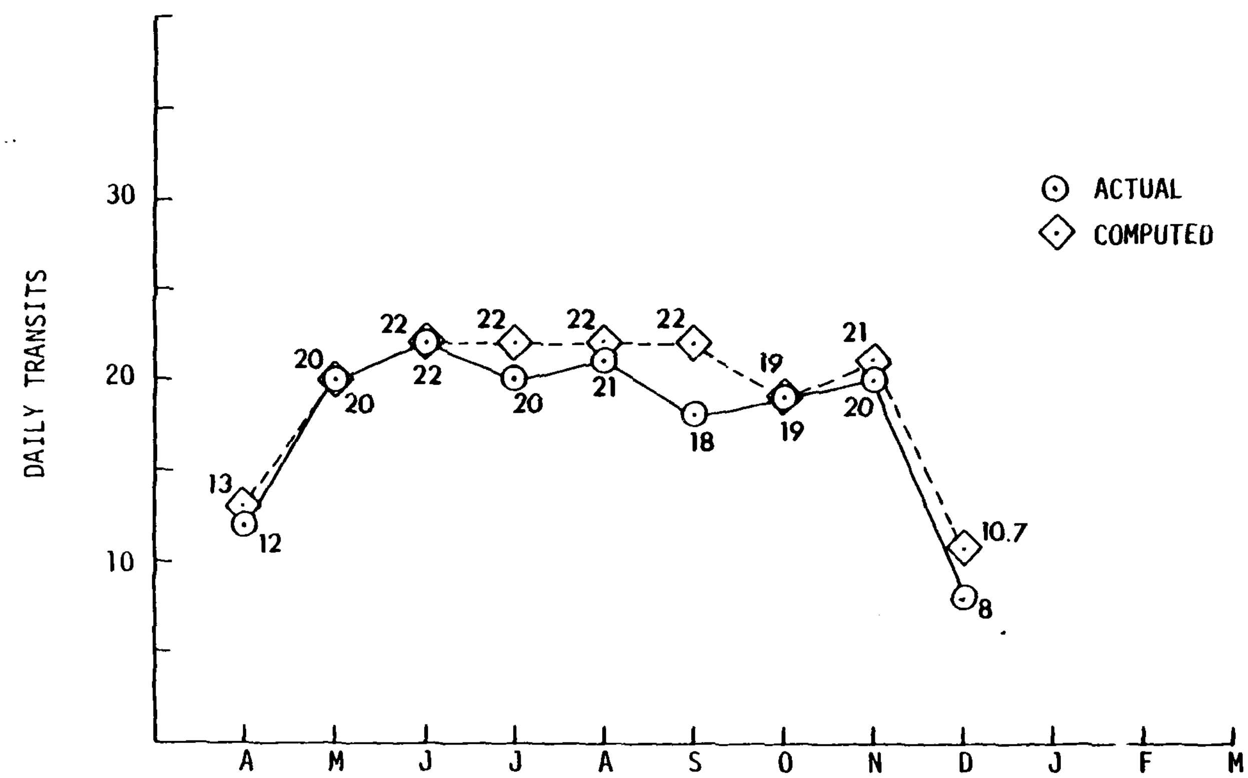


FIGURE 4.8 1976 DAILY TRANSITS BY MONTH FOR ST. LAWRENCE RIVER

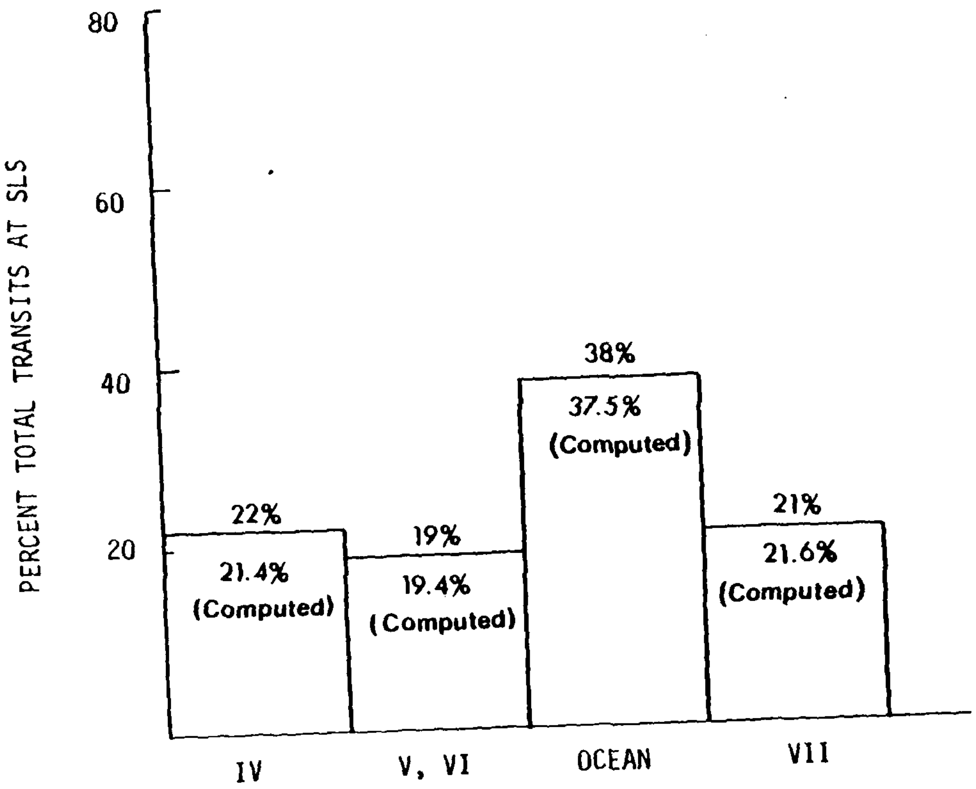


FIGURE 4.9 PERCENT VESSEL TRANSIT BY VESSEL CLASS FOR ST. LAWRENCE RIVER IN 1976

5. CAPACITY ANALYSIS BASE CASE

5.1 Introduction

A capacity analysis of the existing facilities, or base case, was performed as a first step in determining the feasibility of expanding the capacity of the Great Lakes/St. Lawrence Seaway System. This analysis provides a basis against which system capacity expansion measures may be tested.

The GL/SLS System has a guaranteed ship draft at low water datum of 25.5 feet. Over the past several years water levels in the Great Lakes have been significantly higher than the low water datum, allowing ships to operate at drafts of up to 25 feet through the Welland Canal and St. Lawrence River and 27 feet through the Upper Lakes. This increased draft allowed ships to carry more cargo, increasing the tonnage capacity of the GL/SLS System at no cost.

Historically, water levels in the Great Lakes have fluctuated in a cyclic process over periods of decades. Therefore, the present high water levels cannot be assumed to exist throughout the next seventy years. For this reason, two base case analyses were run. The first base case simulated the present system conditions with high water levels and determined capacity assuming these conditions continue to exist. The assumed drafts were 26 feet in the St. Lawrence River and Welland Canal and 27 feet through the Upper Lakes. The second base case simulated the system using the guaranteed ship draft of 25.5 feet. This second base case must be used in this expansion feasibility analysis because 25.5 feet is the only system draft that may be reasonably assumed to exist until the year 2050.

5.2 Cargo Projections

Unconstrained cargo forecasts for the movement of fifteen commodities through the GL/SLS locks were developed by Booz-Allen and Hamilton [6]. These fifteen commodities were grouped into six major commodity categories for use in the lock capacity model as shown in Table 5.1.

In general, the tonnages processed by the locks are expected to increase throughout the period from 1978 through 2050 as shown in Figure 5.1. The Soo Locks will see the largest overall increase, with downbound tonnages increasing from 97,195,000 short tons in 1978 to 246,208,000 short tons in 2050, but a

TABLE 5.1 CARGO COMMODITIES

COMMODITY CATEGORY	INDIVIDUAL COMMODITIES
Grain	Wheat, Soy Beans, Barley and Rye, Corn, Oil Seeds
Stone	Limestone
Iron Ore	Iron Ore
Coal	Coal
Other Bulk	Raw Materials, Petroleum Products, Cement, Non-Metal Minerals, Dry Bulk
General Cargo	General Cargo, Steel Products

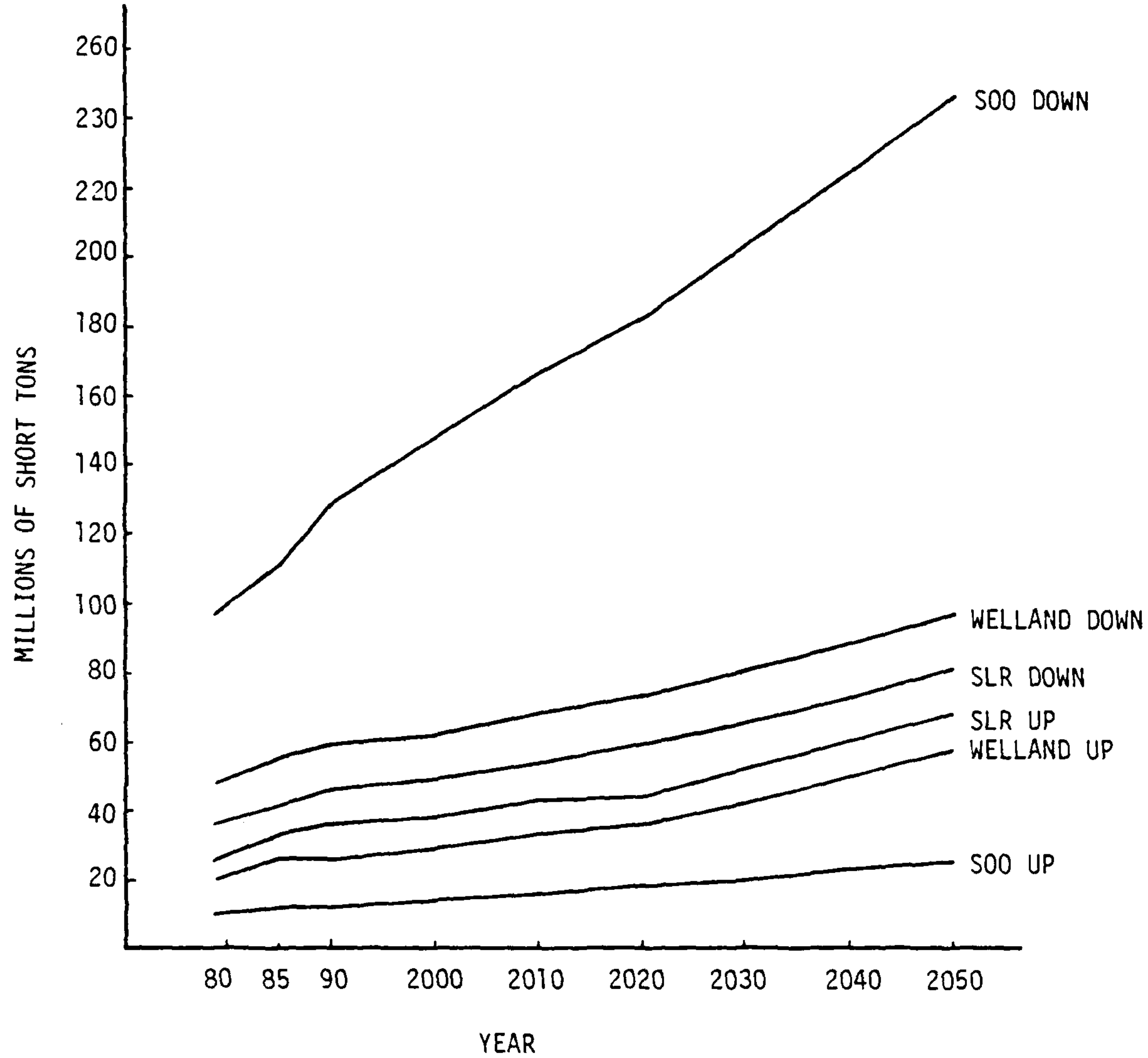


FIGURE 5.1 CARGO PROJECTIONS FOR SOO, WELLAND, AND ST. LAWRENCE RIVER

fairly steady rise is predicted for all of the locks during that period of time. Tonnages are projected to rise approximately 1.3% per year downbound and 1.3% per year upbound at the Soo Locks, 1.0% per year downbound and 1.5% per year upbound at the Welland Canal, and 1.2% per year downbound and 1.4% per year upbound at the St. Lawrence River Locks.

At the Soo Locks, more than 90% of the cargo moves downbound. This percentage is expected to remain constant through 2050. At the Welland Canal, approximately 71% of the cargo moves downbound. This percentage is projected to decrease to approximately 63% over the next 70 years. At the St. Lawrence River, approximately 58% of the cargo moves downbound. This percentage is projected to drop slightly to 54% by the year 2050.

The cargo projections for each of the six commodity categories are discussed in the following paragraphs.

5.2.1 Iron Ore

Iron ore comprises the largest single commodity through the Soo Locks, equaling approximately 63% of the total tonnage. This ratio should remain constant because iron ore through the Soo is projected to increase approximately 1.3% per year from 67,877,000 short tons in 1978 to 168,533,000 short tons in 2050. More than 99% of the iron ore through the Soo moves downbound. This ratio is expected to remain constant.

Iron ore is the second largest commodity moving through the Welland Canal, comprising approximately 23% of the total tonnage. Iron ore tonnages are expected to increase approximately 1.1% per year from 16,138,000 short tons in 1978 to 36,123,000 short tons in 2050. Currently, approximately 70% of the iron ore moves upbound at the Welland. This ratio is expected to increase to 78% by 2050.

Iron ore is the second largest commodity group moving through the St. Lawrence River Locks, and is approximately 23% of the total tonnage. This percentage will remain constant since iron ore is expected to increase approximately 1.2% per year from 13,836,000 short tons in 1978 to 33,016,000 short tons in 2050. All of the iron ore through the St. Lawrence River moves upbound. The forecasts for iron ore are shown in Figure 5.2.

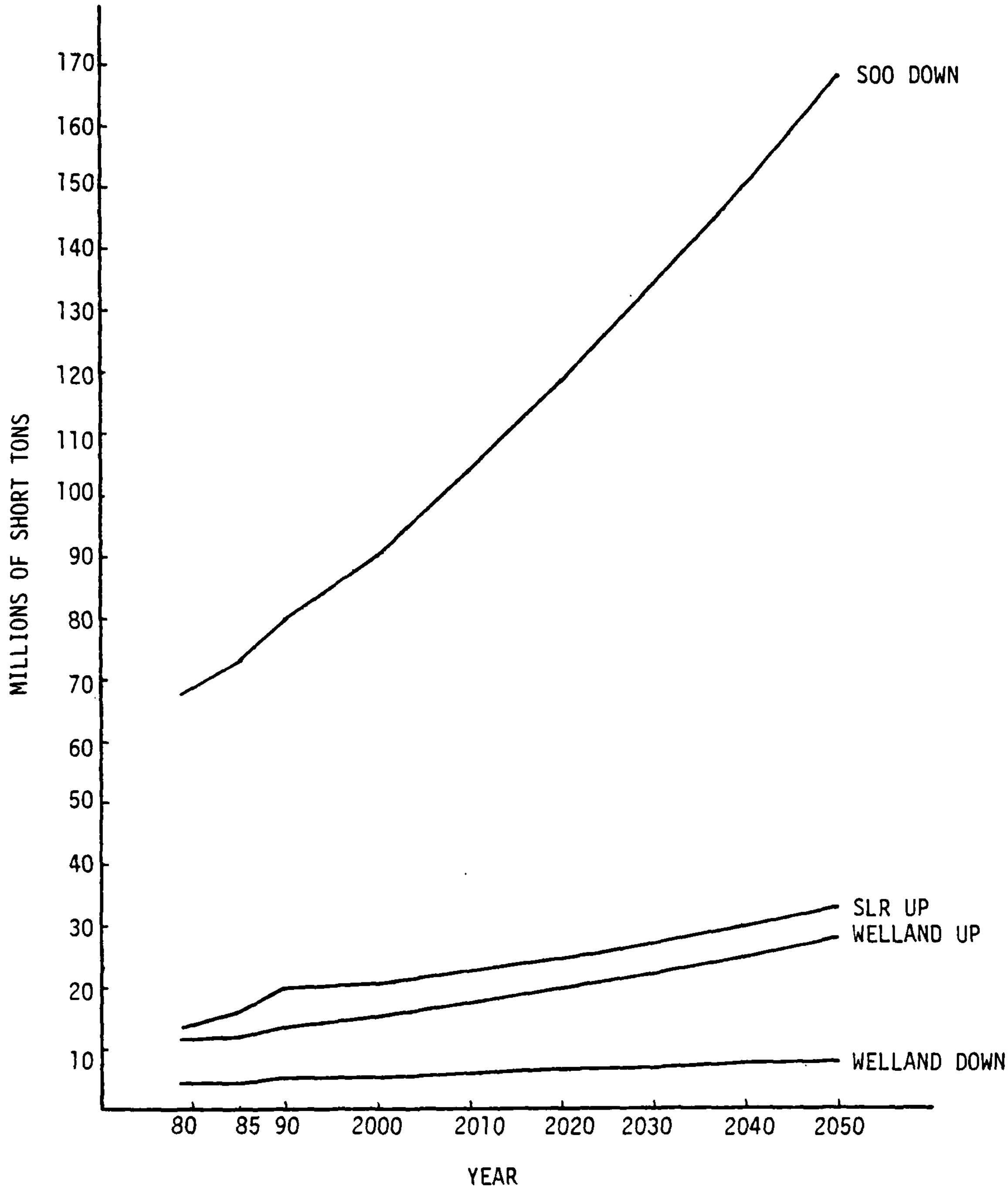


FIGURE 5.2 CARGO PROJECTIONS FOR IRON ORE

5.2.2 Coal

Coal is the third largest commodity moving through the Soo Locks, presently comprising approximately 7% of the total cargo flow. Downbound coal through the Soo Locks is projected to increase at a rate of 6.2% per year from 2,846,000 short tons in 1978 to 19,749,000 short tons in 2010. This will be followed by a period of almost no growth through 2050. Upbound coal is expected to increase at a fairly even rate of 1.1% per year from 4,817,000 short tons in 1978 to 10,939,000 short tons in 2050. In 2050, coal is predicted to comprise approximately 11% of the traffic at the Soo. Presently, approximately 37% of the coal moves downbound. In 2010 the percentage of coal moving downbound will be 75% of the total coal movement. By 2050, the percentage will drop to 62%.

Coal presently accounts for 9% of the total tonnage at the Welland Canal. Virtually no growth is expected for coal at the Welland, with the tonnage remaining approximately 5,700,000 short tons. By 2050 coal will comprise approximately 4% of the Welland total. All of the coal moving through the Welland Canal moves downbound.

Coal accounts for approximately 2% of the tonnage processed by the St. Lawrence River Locks. Coal through these locks is predicted to increase at a rate of 1% per year, from 1,004,000 short tons in 1978 to 2,088,000 short tons in 2050. By 2050 coal will make up approximately 1% of the St. Lawrence River Locks total. More than 99% of the St. Lawrence River coal moves upbound. The coal projections are illustrated on Figure 5.3.

5.2.3 Stone

Stone includes approximately 2% of the total tonnage through the Soo Locks. Stone tonnages are predicted to increase at a rate of approximately 1.3% per year from 1,995,000 short tons in 1978 to 4,955,000 short tons in 2050. All of the stone movement at the Soo Locks is upbound.

The stone estimates for the Welland Canal and the St. Lawrence River Locks are the same. Stone accounts for less than 1% of the total tonnages through both systems. Stone tonnages are expected to increase 1.3% per year, from 156,000 short tons in 1978 to 390,000 short tons in 2050, for both systems. Approximately 70% of the stone through the Welland and the St. Lawrence Locks moves downbound. Stone projections are illustrated in Figure 5.4.

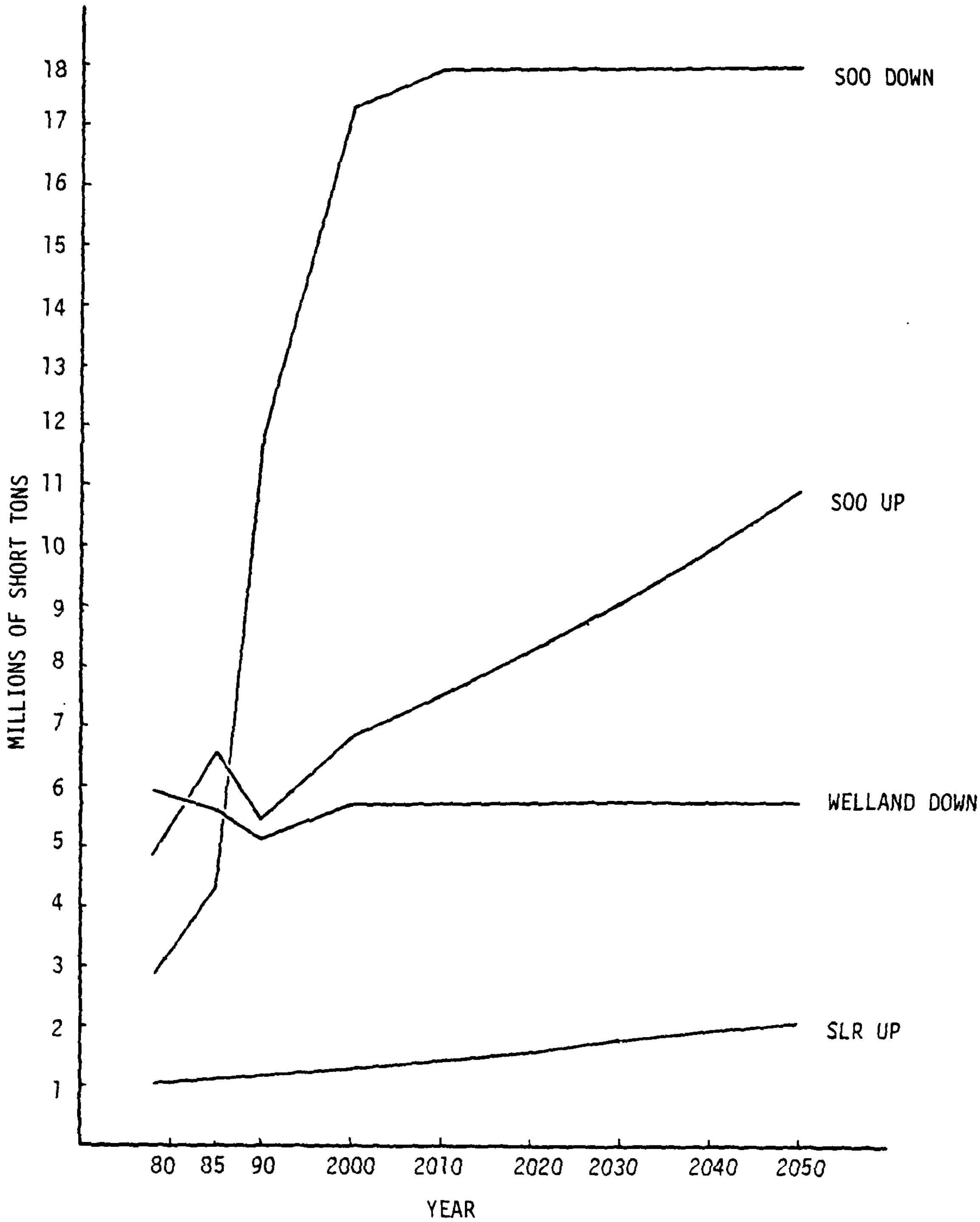


FIGURE 5.3 CARGO PREDICTIONS FOR COAL

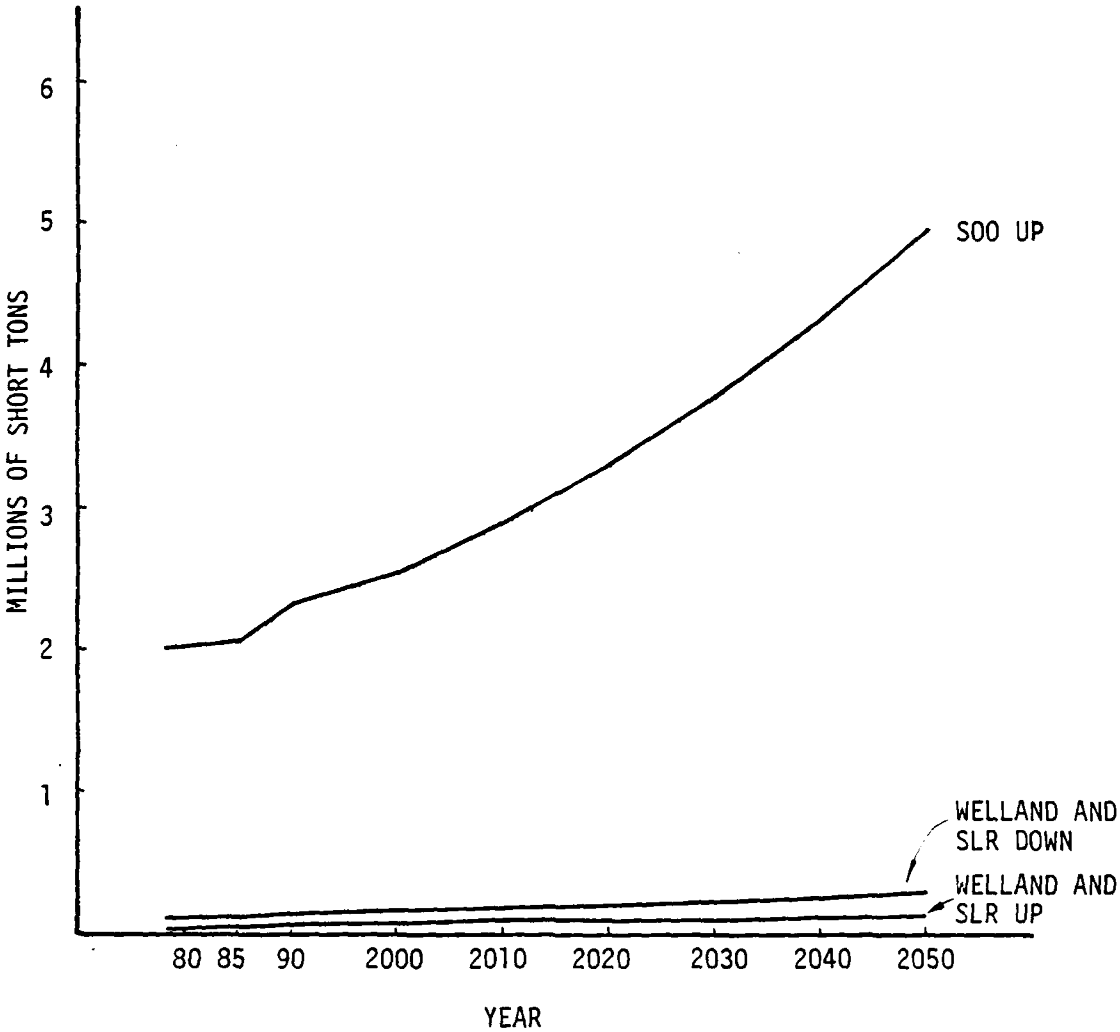


FIGURE 5.4 CARGO PROJECTIONS FOR STONE

5.2.4 Grain

Grain is the second largest commodity category to go through the Soo Locks. Grain accounts for approximately 22% of the tonnage through the Soo. Grain is expected to increase 3.2% per year from 23,856,000 short tons in 1978 to 34,885,000 short tons in 1990, level off with 0.1% per year growth through 2000 to 35,279,000 short tons, and then increase 0.8% per year to 52,416,000 short tons in 2050. By 2050, grain will drop to 19% of the total Soo tonnage. All grain through the Soo is downbound.

Grain is the largest commodity category passing through the Welland Canal, consisting of 44% of the total tonnage. Grain flows through the Welland Canal are projected to increase 2.2% per year until 1990, from 29,761,000 short tons in 1978 to 38,716,000 short tons in 1990, followed by an increase of 0.4% per year to 40,388,000 short tons in 2000, then an increase of 0.8% per year from 2000 to 2050 for a total of 59,707,000 short tons. By 2050 grain will drop to 38% of the total Welland Canal tonnage. More than 99% of all grain through the Welland Canal moves downbound.

Grain is the largest commodity category processed by the St. Lawrence River Locks, consisting of 47% of the total tonnage. The growth pattern for grain in the St. Lawrence River is expected to be similar to that of the Welland and the Soo, rising 2.2% per year from 28,745,000 short tons in 1978 to 37,296,000 short tons in 1990, then 0.4% per year to 38,815,000 short tons in 2000, followed by 0.8% per year to 57,390,000 short tons in 2050. More than 99% of the grain through the St. Lawrence River moves downbound. Grain projections are shown in Figure 5.5.

5.2.5 Other Bulk

Other bulk accounts for 4% of the tonnage processed by the Soo Locks. Other bulk is forecast to increase 1.5% per year downbound, from 1,961,000 short tons in 1978 to 5,804,000 short tons in 2050, and 1.6% per year upbound, from 2,476,000 short tons in 1978 to 8,017,000 short tons in 2050. By 2050 other bulk will comprise 5% of the total Soo tonnage. Approximately 57% of the other bulk transiting the Soo Locks moves upbound.

Other bulk includes approximately 15% of the total tonnage through the Welland Canal. Other bulk is expected to increase 1.6% per year downbound from 6,333,000 short tons in 1978 to 20,466,000 short tons in 2050, and 1.1% per year upbound

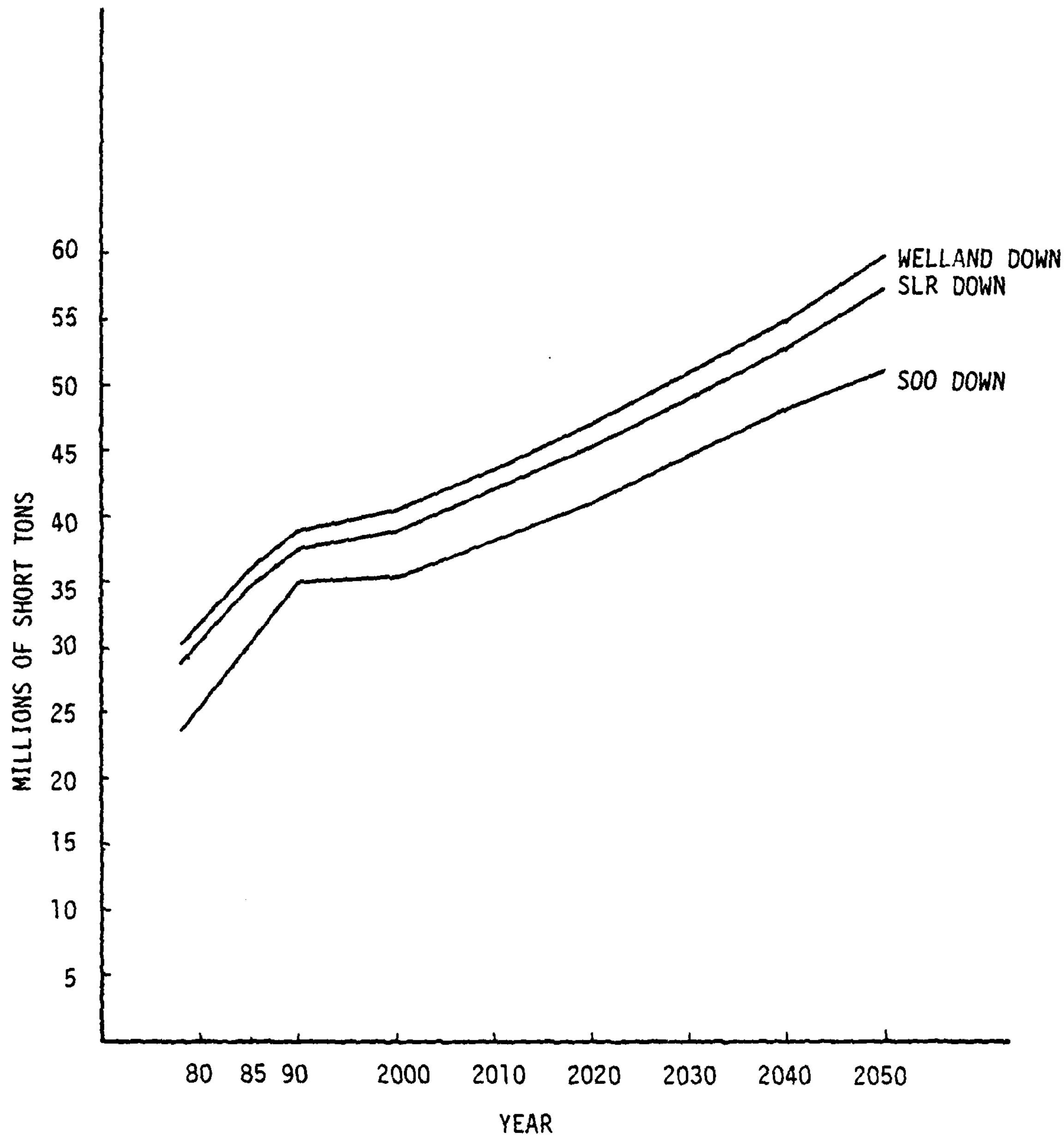


FIGURE 5.5 CARGO PROJECTIONS FOR GRAIN

from 3,863,000 short tons in 1978 to 8,620,000 short tons in 2050. By 2050 other bulk will be 19% of the total tonnage through the Welland Canal. In 1978, 62% of the other bulk moved downbound through the Welland Canal. By 2050 this ratio is expected to be 70% of the total.

Other bulk accounts for approximately 18% of the total tonnage through the St. Lawrence River Locks. Other bulk is predicted to increase 1.7% per year downbound from 5,501,000 short tons in 1978 to 18,916,000 short tons in 2050, and 0.8% per year upbound from 5,302,000 short tons in 1978 to 9,420,000 short tons in 2050. By 2050 other bulk is expected to be 19% of the St. Lawrence River tonnage. In 1978, 51% of the other bulk moved downbound in the St. Lawrence River which is expected to increase to 67% by 2050. Other bulk estimates are illustrated in Figure 5.6.

5.2.6 General Cargo

General cargo is the smallest commodity category moving through the Soo Locks and accounts for approximately 1% of the total tonnage. General cargo is projected to increase approximately 1.1% per year from 833,000 short tons downbound and 736,000 short tons upbound in 1978, to 1,848,000 short tons downbound and 1,651,000 short tons upbound in 2050, remaining approximately 1% of the total projected tonnage. Approximately 53% of the general cargo forecast to transit the lock through 2050 will move downbound.

General cargo makes up approximately 9% of the tonnage processed by the Welland Canal. Upbound general cargo is projected to increase at a fluctuating rate from 4,793,000 short tons in 1978 to 9,069,000 short tons in 2020, followed by an increase of 2.9% per year to 21,118,000 short tons in 2050. Downbound general cargo is estimated to increase approximately 1.5% per year from 1,114,000 short tons in 1978 to 3,166,000 short tons in 2050. By 2050 general cargo is expected to be 16% of the cargo processed by the Welland Canal. In 1978 approximately 81% of the general cargo moved upbound and by 2050, 87% is projected to move upbound at the Welland Canal.

In 1978 general cargo included 11% of the total cargo moving through the St. Lawrence River Locks. The increase in upbound general cargo through the St. Lawrence River Locks is expected to fluctuate from 5,591,000 short tons in 1978 to 10,648,000 short tons in 2020, a 90.4% increase, followed by an increase of 2.7% per year to 23,822,000 short tons in 2050. Downbound general cargo is projected to increase at a rate of

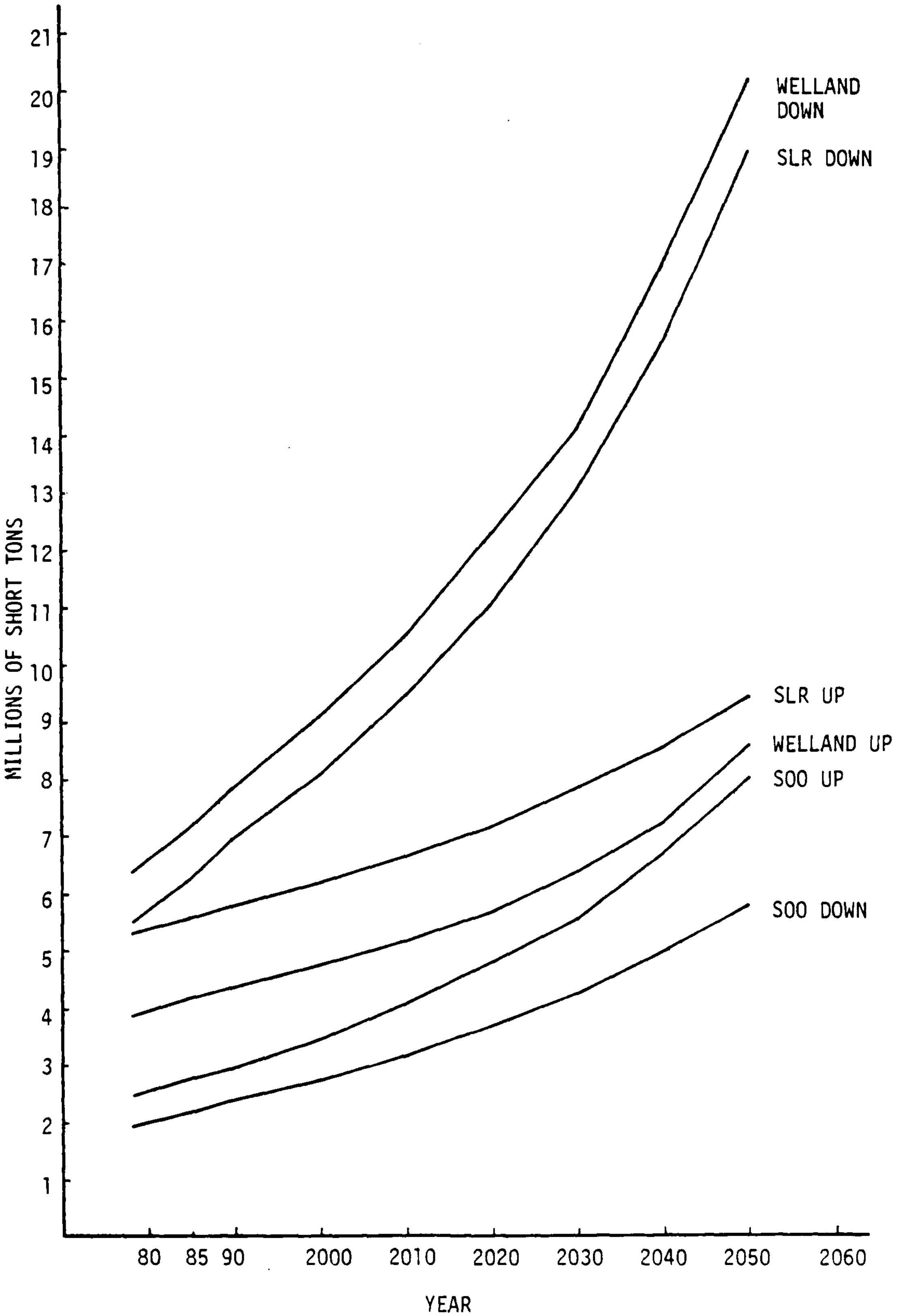


FIGURE 5.6 CARGO PROJECTION FOR OTHER BULK

1.6% per year from 1,312,000 short tons in 1978 to 4,199,000 short tons in 2050. In 2050 general cargo is expected to amount to 19% of the tonnage processed by the St. Lawrence River Locks. In 1978 approximately 81% of the general cargo through the St. Lawrence River Locks moved upbound. By 2050 approximately 85% of the general cargo is projected to move upbound. The predictions for general cargo are shown on Figure 5.7.

5.3 Lockage Time

5.3.1 Brief Description of the Locking Process

Locks were placed on the Great Lakes/St. Lawrence Seaway System to allow passage of vessels where the natural conditions of rapids and water falls made navigation impossible. The locks allow navigation through the waterways while maintaining relatively large differences in water level between the upstream and downstream sides of the lock. The locks also allow for the installation and operation of several hydroelectric power generating stations without preventing vessel use of the System.

Vessels using the locks on the GL/SLS System range in type and size from pleasure craft as small as 20 ft long to ocean and lake carriers 730 ft long and 76 ft wide in the St. Lawrence River Locks, up to laker carriers 1,000 feet long and 105 ft wide at the Soo Locks. The details of the locking process will vary depending on the type and size of the vessel, weather conditions and lockage demand, and on the individual lock characteristics; however, the general locking process remains the same.

A basic lock operating cycle is illustrated in Figure 5.8. When a vessel reaches a lock approach, it will either be told by the lockmaster to proceed into the lock or to moor alongside the approach wall until permission is received to enter the lock. The vessel must wait if the lock is occupied, if the lock is being recycled (turn back), or if there are other vessels waiting first.

After being given the go-ahead, the vessel will proceed into the lock at a safe rate of speed as instructed by the lockmaster, and as dictated by the locking procedures for that particular lock. When the vessel has entered the lock, it will be moored. One or more vessels may be brought into the lock if vessel sizes permit a tandem or multiple vessel lockage. Once the vessel(s) are in place, the rearward gates of the lock will be closed. The required valves will be opened and the chamber

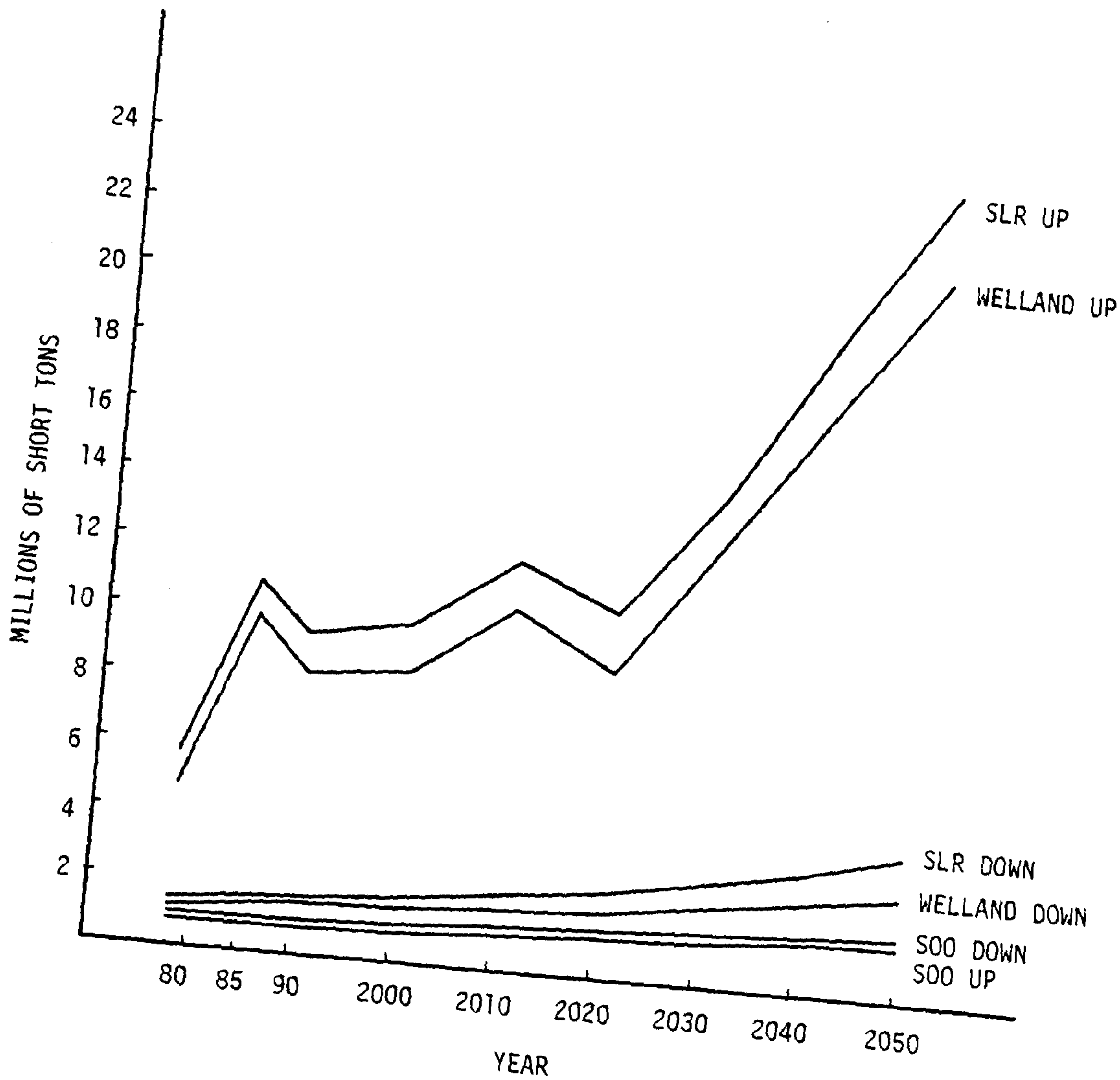
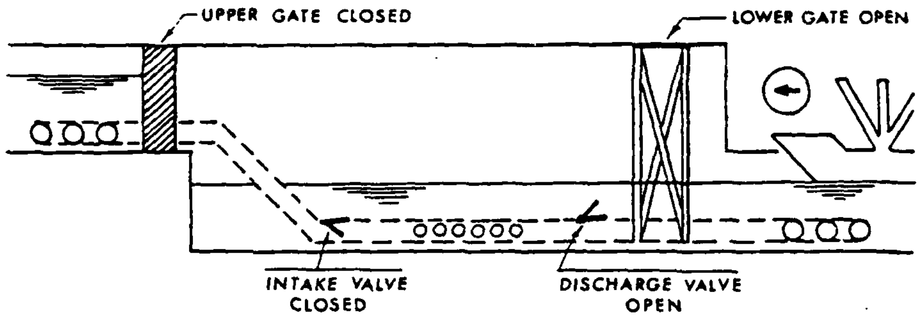
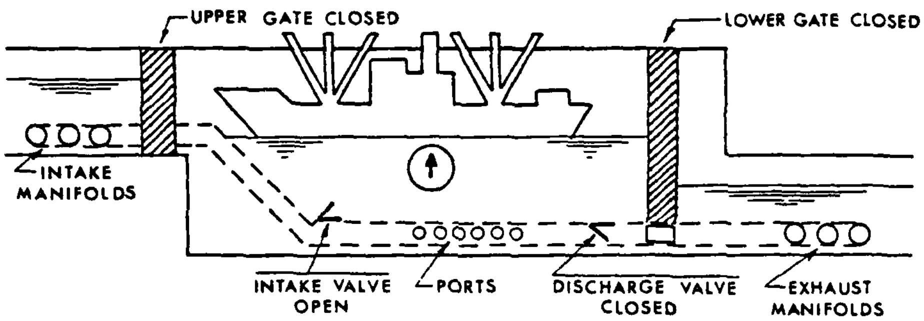


FIGURE 5.7 CARGO PROJECTIONS FOR GENERAL CARGO

STEP 1; VESSEL ENTERING THE LOCK



STEP 2; FILLING OF THE LOCK



STEP 3; VESSEL LEAVING THE LOCK

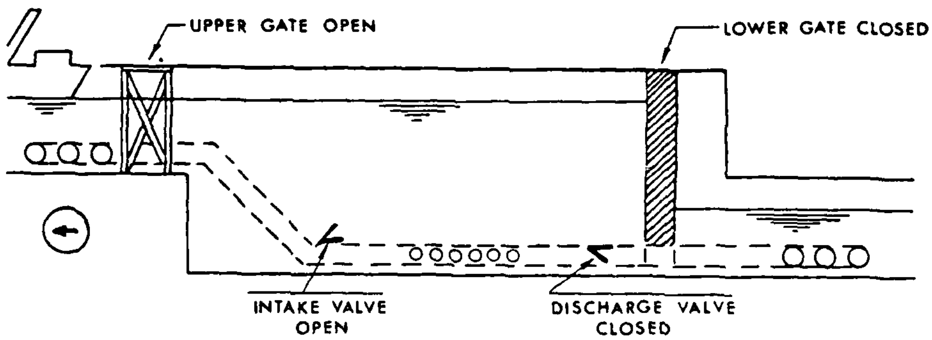


FIGURE 5.8 BASIC LOCKING PROCESS

will be emptied (dumped) or filled depending on whether the vessel is transiting from higher or lower, or lower to higher water. This process is called chambering. When the new water level has been reached, the forward gates will be opened, the mooring lines will be cast off, and the vessel(s) will proceed out of the lock.

5.3.2 Selection of Lockage Times

The time required to process a vessel through a lock (locking time) can be broken down into a small or large number of components. One of the more elementary breakdowns consists of three components as follows:

Entrance Time - time from vessel arrival to vessel mooring inside the lock;

Chambering Time - time required to close the rearward gate, empty or fill the lock, and open the forward gates;

Exit Time - time from completion of chambering until the lock is ready to accept another vessel.

The length of the locking time is dependent upon individual lock characteristics, vessel characteristics, the preceding lock cycle, weather conditions, level of traffic, and equipment failures.

The lock characteristics mainly affect chambering time. Gate opening and closing times are basically functions of the operating machinery. Dump/fill times are functions of the size of the chamber and the lock culverts. In general, differences in chambering time because of differences between lock designs are negligible.

Vessel characteristics will have no affect on dump/fill times because the amount of water which must be moved into or out of the lock is independent of ship size. However, large vessels, especially those approaching maximum vessel size for the lock, have large entrance and exit times. The larger ships must move slower and require extra maneuvering time in order to safely enter and exit the lock and clear other vessels.

During periods of equal amounts of upbound and downbound traffic, vessels can be locked "on the fly". That is to say, vessels are locked in alternate upbound and downbound directions,

eliminating the need for turnback lockages. When traffic is primarily in one direction, turn-back lockages are required. After a vessel is locked through, the gates must be turned back so that the next vessel can be taken from the same direction.

Adverse weather conditions may increase locking times or cause shutdown of the locks altogether. During early or late season operations, large accumulations of ice in the lock and lock throat may require separate ice lockages. Fog may cause lock shutdown because of visibility problems. High winds may make vessels with large broadside areas unmanageable, causing them to be temporarily prohibited from using the lock.

Maintenance schedules have been arranged to minimize their impact on locking times; however, temporary delays may still occur because of equipment failure. The rate of these failures increases when the navigation season is extended into winter operations.

Looking at the breakdown of locking time in more detail, the lock service time (t_ℓ) for normal season operations can be expressed as:

$$t_\ell = t_{approach} + t_{entry} + t_{process} + t_{\text{chamber exit}} + t_{\text{throat exit}}$$

where

$$t_{process} = t_{\text{gate closing}} + t_{securing} + t_{\text{dump/fill}} + t_{\text{gate opening}} + t_{unsecuring}$$

and

t_ℓ = time required to lock a ship (min)

$t_{approach}$ = time for a ship to move from clear point to point where bow is over entrance sill (min)

t_{entry} = time from point of bow over sill to point where entrance gates can close (min)

$t_{\text{gate closing}}$ = time for entrance gates to close (min)

$t_{securing}$ = time for a ship to secure (min)

$t_{dump/fill}$ = time for lock to dump or fill (min)

$t_{gate\ opening}$ = time for exit gates to open (min)

$t_{unsecuring}$ = time for a ship to unsecure (min)

$t_{chamber\ exit}$ = time for stern of ship to pass over exit sill (min)

$t_{throat\ exit}$ = time for ship to move from its stern over sill to when the ship has passed the exit clear point and another ship can begin the locking process from the other direction.

It would be desirable to have a large data base for locking time components that could then be analyzed to determine a mean and frequency distribution for each component. In reality, this data does not exist for any system other than the Welland Canal. In order to obtain the required time component data for each of the three lock systems, the following approach was taken.

Welland Locks: The St. Lawrence Seaway Authority (SLSA) has done a significant amount of lock record analysis to generate mean locking times and the associated standard deviation by vessel class and direction. The results of that analysis for one full year of lock records is presented in Tables 5.2 and 5.3. Based on conversations with SLSA personnel, the comment was made several times that while this was the best data available, they felt they needed more than a full year of data to have a statistically significant data base. In summary, based on their analysis, Lock 7 was found to be the most constraining lock in terms of locking time, while Locks 1, 2, and 3 all had almost the same locking time (approximately 5 to 7 minutes less than that at Lock 7), and the total locking time at the flight locks (Locks 4, 5, and 6) was approximately 30 to 35 minutes depending on the ship class.

St. Lawrence River Locks: At the St. Lawrence Locks, data on locking times are not as complete and detailed as that available for the Welland. Following the recommendation of the SLSA and SLSDC personnel, the locking times of the St. Lawrence Locks are assumed to be the same as those of the non-constraining locks (Locks 1, 2, and 3) in the Welland Canal. The percent difference between constraining and non-constraining locking times

TABLE 5.2 LOCK TIMES FOR THE WELLAND CANAL CONSTRAINING LOCK

														Total Locking Time			
				$t_{approach}$		t_{entry}		$t_{in\ lock}$*		$t_{chamber\ exit}$		$t_{throat\ exit}$		t_{total}		σ	
Vessel Class	Gate Open	Gate Closed	Dump/ Fill	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound
IV	1	1	9	9	9	5	5	11	13	4	4	6	8	35	39	2.7	2.8
V	1	1	9	9	9	5	5	11	13	4	4	6	8	35	39	2.7	2.8
VI	1	1	9	12	13	7	7	12	13	6	6	8	8	45	47	3.5	3.8
VII	1	1	9	14	13	7	8	12	13	6	6	8	8	47	48	4.1	4.1

NOTES: *includes column 1, 2, 3, and securing and unsecuring.

SOURCES: All data was developed from "Welland Canal Single Lock Analysis" summary sheets. The constraining lock was considered to be Lock 7.

TABLE 5.3 LOCK TIMES FOR THE WELLAND CANAL NONCONSTRAINING LOCKS

				$t_{approach}$		t_{entry}		$t_{in\ lock}$*		$t_{chamber\ exit}$		$t_{throat\ exit}$		Total Locking Time t_{total}		Total Locking Time σ	
Vessel Class	Gate Open	Gate Closed	Dump/ Fill	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound
IV	1	1	9	7	7	5	5	13	13	4	4	5	5	34	34	2.7	2.7
V	1	1	9	7	7	5	5	13	13	4	4	5	5	34	34	2.7	2.7
VI	1	1	9	7	9	7	7	13	13	6	6	6	5	39	40	2.8	2.8
VII	1	1	9	8	9	7	8	14	13	6	6	6	5	41	41	3.0	3.0

NOTES: *includes column 1, 2, 3, and securing and unsecuring.

SOURCES: All data was developed from "Welland Canal Single Lock Analysis" summary sheets. The constraining locks were Locks 1, 2, and 3.

was assumed to be the same at the Welland and at the St. Lawrence River, allowing determination of the St. Lawrence River non-constraining locking times. A summary of the locking time data for the St. Lawrence Locks is presented in Tables 5.4 and 5.5.

Soo Locks: Similar to the St. Lawrence situation, data on locking times at the Soo are not as complete and detailed as that available for the Welland. At the Soo, the only locking time data collected are the time from when the bow passes over the entrance sill until when the stern passes over the exit sill. Data on entrance and exit times are not available. In order to estimate these entrance and exit times, conversations were held with the lock operators to determine where the clearing points were defined, and what practical assumptions could be made in order to obtain the data needed. Based on those discussions, it was decided to estimate the entrance and exit times by assuming that the average speed of advance of vessels entering the lock is approximately 1.0 mph, and the average speed of advance of vessels leaving the lock is approximately 2.0 mph. Using this approach, along with locking data from the Sabin-Davis Lock Model and data gathered by Penn State at the Soo, the locking time data, presented in Tables 5.6 and 5.7, were derived.

5.4 Fleet Mix

5.4.1 Significance of Fleet Mix Determination

The Great Lakes/St. Lawrence Seaway System services lake-bound ships (lakers) and oceangoing ships (salties). The number, size (or vessel class), and carrying capacity of the ships that operate on the GL/SLS System plan an important role in determining the capacity of the system.

Table 5.8 gives the characteristics of the vessels that the GL/SLS Lock Capacity Model assumes operate through the Great Lakes and St. Lawrence Seaway. As is noted on the table, all oceangoing ships longer than 400 feet are classified Class 6. Lake ships 600 to 699 feet (conventional Classes 5 and 6) are called Class 5 by the model.

Larger ships carry more cargo in proportion to their locking time than do smaller ships. Therefore, recognizing that the system constraint is in terms of the number of lockages that can be completed per day, as the ships in the fleet get larger, because of the retirement of small ships and the construction of larger ships, the capacity of the locking system increases. The composite ship class can be used as an indicator of the size

TABLE 5.4 LOCK TIMES FOR THE SLR CONSTRAINING LOCKS

	1	2	3	4		5		6		7		8		9 Total Locking Time			
				$t_{approach}$		t_{entry}		$t_{in\ lock}$*		$t_{chamber\ exit}$		$t_{throat\ exit}$		t_{total}		σ	
Vessel Class	Gate Open	Gate Closed	Dump/ Fill	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound
IV	2	2	7	7	7	5	5	13	13	4	4	5	5	34	34	2.7	2.7
V	2	2	7	7	7	5	5	13	13	4	4	5	5	34	34	2.7	2.7
VI	2	2	7	7	9	7	7	13	13	6	6	6	5	39	40	2.8	2.8
VII	2	2	7	8	9	7	8	14	13	6	6	6	5	41	41	3.0	3.0

NOTES: * includes column 1, 2, 3 and securing and unsecuring.

SOURCES: Following the recommendations of SLSA and SLSDC personnel, the locking times for the SLR constraining lock was assumed to be the same as the Welland Canal nonconstraining locking times.

1, 2, 3: Peter, J. J. and T. V. Kotras, "Simulation of Lock Operations During Winter Ice Months," Proceedings of the Third International Symposium on Ice Problems, International Association of Hydraulic Research, Nov. 1975, pp. 49-58.

TABLE 5.5 LOCK TIMES FOR THE SLR NONCONSTRAINING LOCK

Vessel Class	1 Gate Open	2 Gate Closed	3 Dump/ Fill	4 $t_{approach}$ Down-bound	4 $t_{approach}$ Up-bound	5 t_{entry} Down-bound	5 t_{entry} Up-bound	6 $t_{in\ lock}$* Down-bound	6 $t_{in\ lock}$* Up-bound	7 $t_{chamber\ exit}$ Down-bound	7 $t_{chamber\ exit}$ Up-bound	8 $t_{throat\ exit}$ Down-bound	8 $t_{throat\ exit}$ Up-bound	9 Total Locking Time t_{total} Down-bound	9 Total Locking Time t_{total} Up-bound	9 Total Locking Time σ Down-bound	9 Total Locking Time σ Up-bound
IV	2	2	7	5	5	5	5	13	13	4	4	4	4	31	31	2.3	2.3
V	2	2	7	5	5	5	5	13	13	4	4	4	4	31	31	2.3	2.3
VI	2	2	7	6	6	7	7	13	13	6	6	4	4	36	36	2.7	2.7
VII	2	2	7	6	6	7	8	14	13	6	6	4	4	37	37	2.8	2.8

NOTES: *includes column 1, 2, 3, and securing and unsecuring.

SOURCES: 1, 2, 3: Same as SLR Constraining Lock data.

4, 8: The difference between the SLR constraining and nonconstraining data in columns 4 and 6 approximate the differences between the constraining and nonconstraining data in columns 4 and 6 for the Welland Canal. This is due to the fact that approach and exit times are a function of the amount of usage of the lock.

5, 6, 7: These times are assumed to be functions of vessel class only, therefore they are the same for constrainining and nonconstraining locks.

9: Kotras, T., J. Kim, and J. Jacobi, "Technical Appendices-Great Lakes/St. Lawrence Seaway Lock Capacity Analysis," *Vol. II*, *ARCTEC, Incorporated Report* 478C-4, April 1979.

TABLE 5.6 LOCK TIMES FOR THE MACARTHUR/POE SET OF SOO LOCKS

	1	2	3	4		5		6		7		8		9 Total Locking Time			
				$t_{approach}$		t_{entry}		$t_{in\ lock}$*		$t_{chamber\ exit}$		$t_{throat\ exit}$		t_{total}		σ	
Vessel Class	Gate Open	Gate Closed	Dump/Fill	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound
IV	2	2	7	15	10	12	7	29	28	8	10	9	13	73	68	6.3	9.0
V	2	2	7	17	8	13	8	28	26	8	10	9	13	75	65	6.7	9.3
VI	2	2	6	18	9	14	9	26	23	7	11	9	13	74	65	6.2	9.3
VII	2	2	7	19	7	14	9	28	21	7	11	9	13	77	61	6.3	9.7
VIII	2	2	7	21	6	14	9	23	27	9	11	11	15	78	68	3.5	5.3
IX	2	2	7	26	10	15	10	34	26	14	13	12	14	101	73	6.3	5.7
X	2	2	6	24	9	15	10	43	42	12	14	12	14	106	89	5.5	7.3
XI	2	2	6	26	10	15	10	47	49	14	15	12	14	115	98	5.1	7.3

NOTES: *includes column 1, 2, 3, and securing and unsecuring.

SOURCES: 1, 2, 3, 4: Based on the definition of $t_{approach}$ for this table, and the definitions of long entry and short entry times utilized in the Sabin-Davis model, this column is the difference between the Sabin-Davis short entry time and long entry time data.

5, 7: Comparison between Sabin-Davis short entry time and times calculated for a vessel entering a lock at approximately 1 mph.

6: Comparison of Sabin-Davis chamber cycle time and data developed from Soo lock records.

8: Developed from information obtained from conversations with lock operators.

9: Kotras, T., J. Kim, and J. Jacobi, "Technical Appendixes-Great Lakes/St. Lawrence Seaway Lock Capacity Analysis," Vol. II, ARCTEC, Incorporated Report No. 478C-4, April 1979.

TABLE 5.7 LOCK TIMES FOR THE SABIN-DAVIS SET OF SOO LOCKS

	1	2	3	4		5		6		7		8		9 Total Locking Time			
				$t_{approach}$		t_{entry}		$t_{in\ lock}$*		$t_{chamber\ exit}$		$t_{throat\ exit}$		t_{total}		σ	
Vessel Class	Gate Open	Gate Closed	Dump/ Fill	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound
IV	2	2	7	8	7	5	5	15	14	4	3	7	8	39	38	2.8	2.5
V	2	2	7	9	8	6	6	15	14	5	5	7	8	42	41	3.2	2.8
VI	2	2	7	9	8	7	7	15	14	6	6	7	8	44	43	2.7	4.0
VII	2	2	7	10	8	7	7	15	14	6	6	7	9	45	44	2.8	3.5
VIII	2	2	7	10	8	8	8	15	14	7	7	8	9	48	46	3.0	2.2

NOTES: *inc[illegible]s column 1, 2, 3, and securing and unsecuring.

SOURCES: 1, 2: Same as reference for SLR Constraining Locks.

4, 8: Developed from information obtained from conversations with lock operators.

5, 6, 7: Based on vessel entry and exit speeds, and Welland and SLR data.

9: Kotras, T., J. Kim, and J. Jacobi, "Technical Appendices-Great Lakes/St. Lawrence Seaway Lock Capacity Analysis," Vol. II, ARCTEC, Incorporated Report No. 478C-4, April 1979.

TABLE 5.8 VESSEL CHARACTERISTICS

VESSEL CLASS	VESSEL LENGTH RANGE (ft)		MEAN VESSEL SPEED (mph)	MAXIMUM CARRYING CAPACITY[1] (short tons)	LOCKING TIME (min)		CAPACITY INCREASE WITH DRAFT (short tons/in)
	MIN	MAX			UP	DN	
4	0	599	13.8	9500	59	64	0.0
5	600	699	13.9	21000	57	65	91.8
6	400	699	14.7	15000	57	64	61.8
7	700	749	14.7	27000	53	67	113.1
8	750	849	14.9	28000	59	68	115.6
9	850	989	14.9	45000	64	88	167.1
10	990	1099	14.9	60000	77	92	207.1
11	1100	1199	14.9	72000	85	100	228.6
12	1200	1299	14.9	90000	98	110	250.0

Class 5 is lakers of Classes 5 and 6.

Class 6 is ocean-going vessels.

NOTES: 1. Maximum Carrying Capacity at low water datum. Maximum ship draft equals 25.5 ft.

of the vessel fleet. If the composite ship class of the fleet utilizing a lock system increases with time, the tonnage capacity of that lock system will also increase. Composite ship class for a given fleet is obtained as follows:

$$CSC = \frac{\sum_{LC=1}^{LU} LC \times \text{SHIP}\ (LC)}{\sum_{LC=1}^{LU} \text{SHIP}\ (LC)}$$

where

LC = vessel class

LU = largest vessel class in fleet

SHIP(LC) = number of ships of each vessel class in fleet.

5.4.2 Fleet Mix for the Base Case

A task report to the Corps of Engineers entitled "Great Lakes/St. Lawrence Seaway Fleet Mix" [7] describes the general economic and operating conditions that determine the fleet mix. This section describes the way in which fleet growth percentages were determined for each ship class and commodity for use in the GL/SLS Lock Capacity Model. The model uses these fleet growth predictions with projected commodity demand to compute the fleet size in future years.

Commodity demand plus the availability and size of port facilities ultimately determine the composition of future fleets; however, the way in which operators change their fleet composition also depends on general economic conditions. These conditions include the costs of operating small ships to serve small ports, the costs of labor, the price of fuel, the fuel efficiency of various sizes and classes of ships, and the capital costs involved in building new ships.

This section reviews the way in which ships are added for the base case; that is, the case in which the fleet changes to meet commodity demand but no physical or operational changes are made in the lock systems. These fleet growth computations assume that each lock system serves a separate fleet. For example, the Soo Locks fleet is assumed to include all the ships that use the Soo Locks system; U.S., Canadian, and foreign. Similar assumptions are made for the fleets for the Welland Canal and the St. Lawrence River.

Table 5.9 shows the percent growth for each ship class to meet commodity demand for the Soo Locks System. The numbers show the percent that each ship class is expected to increase to meet increased demand for a particular commodity. As an example, for ore, new construction to meet additional demand is expected to be 10% Class 5 ships, 20% Class 7 ships, and so forth. The paragraphs that follow describe the specific conditions that were considered to determine percent growth for each ship class. Table 5.10 provides the same information for the Welland Canal and St. Lawrence River. A similar table and description will also be provided for new fleet growth patterns that are expected to occur in response to structural changes to the locks systems.

5.5 Results of Base Case Analysis

5.5.1 Definition of Capacity

For the purposes of this study, capacity at one of the lock systems on the GL/SLS System is defined as an average lock utilization of 90% for the high demand months of May through November. Lock utilization is the ratio of the time the lock is actually processing ships to the total time available for ship processing, expressed as a percent. Lock utilization of 90% generally results in an average vessel waiting time of approximately six hours and an average queue length of four ships. Lock utilizations of greater than 90% may result in much larger waiting times and queue lengths, because these quantities increase exponentially near capacity.

5.5.2 Higher Water Level Base Case

The high water base case assumes an allowable ship draft of 27 feet at the Soo and 26 feet at the Welland Canal and St. Lawrence River.

5.5.2.1 Soo Locks - Based on the input data explained in the previous sections (cargo projections, lock characteristics, and fleet mix) and a capacity definition of 90% lock utilization, capacity at the Soo Locks will be reached in the year 2010. The tonnage processed through the Soo Locks at capacity will be 182,251,000 short tons. This assumes that the higher water levels that allow ships to operate at up to 27 feet of draft will remain until this time.

The capacity tonnage of 182,251,000 short tons is an increase of 74,861,000 short tons or 69.7% over the 107,390,000 short tons processed through the Soo Locks in 1978. This

TABLE 5.9 SOO LOCKS BASE LINE FLEET % ADDED TO EACH CLASS

CLASS	ORE	COAL	STONE	GRAIN	OTHER BULK	GENERAL CARGO
4	0	0	0	0	30	20
5*	10	10	40	10	60	0
6**	0	5	0	20	0	80
7	20	40	60	70	10	0
8	10	15	0	0	0	0
9	0	0	0	0	0	0
10	60	30	0	0	0	0

*Class 5 and 6 Lakers
**Ocean Class

- Ore - The U.S. operators will continue to build Class 5 and 6 ore carriers because of port limitations. There are no foreign ore carriers using the Soo, therefore Class 6 is zero. Canadian Class 7 ships will continue to be important. Some Class 8 ships will be built for U.S. trade, but the preponderance of new ore ships are expected to be Class 10.

- Coal - Some Class 5 and 6 lakers are expected to be added to serve small ports. Some Class 6 foreign ships are expected to haul coal, but the numbers are expected to be low. Class 7 ships will be used to carry coal to Canadian ports on Lake Ontario and for transshipment to overseas ports. There will continue to be an important growth of Class 8 and 10 ships for coal shipments to ports on the Lakes.

- Stone - Most U.S. ships in the stone trade are Class 5 and 6. No foreign ships are expected to carry stone through the Soo. As the stone trade expands, a shift to Class 7 ships is expected, but not larger ships.

- Grain - Carriers taking grain out of Lake Superior are distributed as follows: U.S., 6.9%; Canadian, 70.4%; and foreign, 22.7%. Old Class 5 ships are presently used in the U.S. grain trade, but if the U.S. share of the trade increases, operators are likely to move to larger ships. Nearly all Canadian ships hauling grain are Class 7. If the locks at the Welland and the St. Lawrence River do not increase in size, this trend is expected to continue.

TABLE 5.9 SOO LOCKS BASE LINE FLEET % ADDED TO EACH CLASS (CONTINUED)

- Other Bulk - This category includes sand, salt, raw materials, cement, and petroleum products. These commodities are carried in the smallest ships although in future years there could be some expansion into Class 7 vessels.

- General Cargo - General cargo is carried in the smallest of the lakers, often package freighters that are less than 100 feet long, plus ocean class vessels. This trend is expected to continue.

TABLE 5.10 WELLAND CANAL AND ST. LAWRENCE RIVER
BASE LINE FLEET

CLASS	ORE	COAL	STONE	GRAIN	OTHER BULK	GENERAL CARGO
4	0	0	0	0	20	20
5*	20	10	20	5	30	0
6**	0	10	10	35	30	80
7	80	80	70	60	20	0

*Class 5 and 6 Lakers
**Ocean Class

- Ore - Upbound ore comes from Labrador and goes to Lake Ontario and U.S. ports. Downbound ore goes to steel mills in Lake Ontario. Some ore moves in Class 5 and 6 lakers but most is carried in Canadian Class 7's.

- Coal - Most coal shipments are downbound from the U.S. to Lake Ontario ports. This is generally carried in Canadian Class 7 ships. Some coal moves in ocean class ships.

- Stone - Some stone is carried U.S. to Canada in Class 5 ships, but most is carried Canada to Canada or Canada to U.S. in Canadian Class 7's.

- Grain - Grain shipments through the Welland Canal are 64% Canadian, 36% foreign, and 0.6% U.S. Building predictions reflect this distribution.

- Other Bulk - Most of this cargo is carried in small lakers although some coke comes through in foreign ships. Some future building of Class 7's is expected.

- General Cargo - General cargo moves in the smallest lakers and in ocean class.

increase in tonnage is mainly the result of a 256% increase in coal, a 54% increase in iron ore, and a 60% increase in grain.

In order to transport the increased commodities, the Soo fleet increased 41.7%, from 108.5 ships in 1978 to 153.7 ships in 2010. At the same time, system capacity was increased as smaller ships were retired and larger ships were constructed. The composite ship class for the Soo Locks increased from 6.4 in 1978 to 7.0 in 2010. The greatest increases in ship size came in iron ore and coal carriers. The composite ore carrier ship class increased from 6.9 in 1978 to 8.4 in 2010, and the composite coal ship class increased from 6.1 in 1978 to 7.8 in 2010. The Soo fleet mix from 1978 through 2010, according to ship class, is shown in Figure 5.9.

The total number of transits through the Soo Locks increased from 7,698 in 1978 to 10,665 in 2010. This increase of 38.5%, compared with the tonnage increase of 69.7%, is a further indication of the increased capacity of the fleet due to the construction of larger ships. There was no change in the ratio of loaded to total transits.

The constraining locks at the Soo are the Poe and the MacArthur. Both locks approach capacity with almost equal lock utilization, averaging 91.4% at the MacArthur and 90.3% at the Poe for the peak period from May to November. Near capacity, however, the queue lengths and waiting times are slightly longer at the Poe than at the MacArthur. This is because the Poe handles large ships with longer locking times, while the MacArthur handles more ships, but of smaller size and shorter locking time. During the period of heaviest traffic in July, the Poe had a lock utilization of 91%, an average waiting time of 3.0 hours upbound and 13.1 hours downbound, and an average queue length of 0.7 vessels upbound and 4.4 vessels downbound. The MacArthur lock had its heaviest traffic in May, when lock utilization reached 95%; the average waiting time was 0.3 hours upbound and 11.4 hours downbound, and the average queue length was 0.03 vessels upbound and 7.0 vessels downbound.

Operation of the Davis Lock was not required because lock utilization at the Sabin remained less than 50%. Utilization at the Sabin Lock tended to decrease slightly with time because the smaller ships that use the Sabin or Davis Locks were retired.

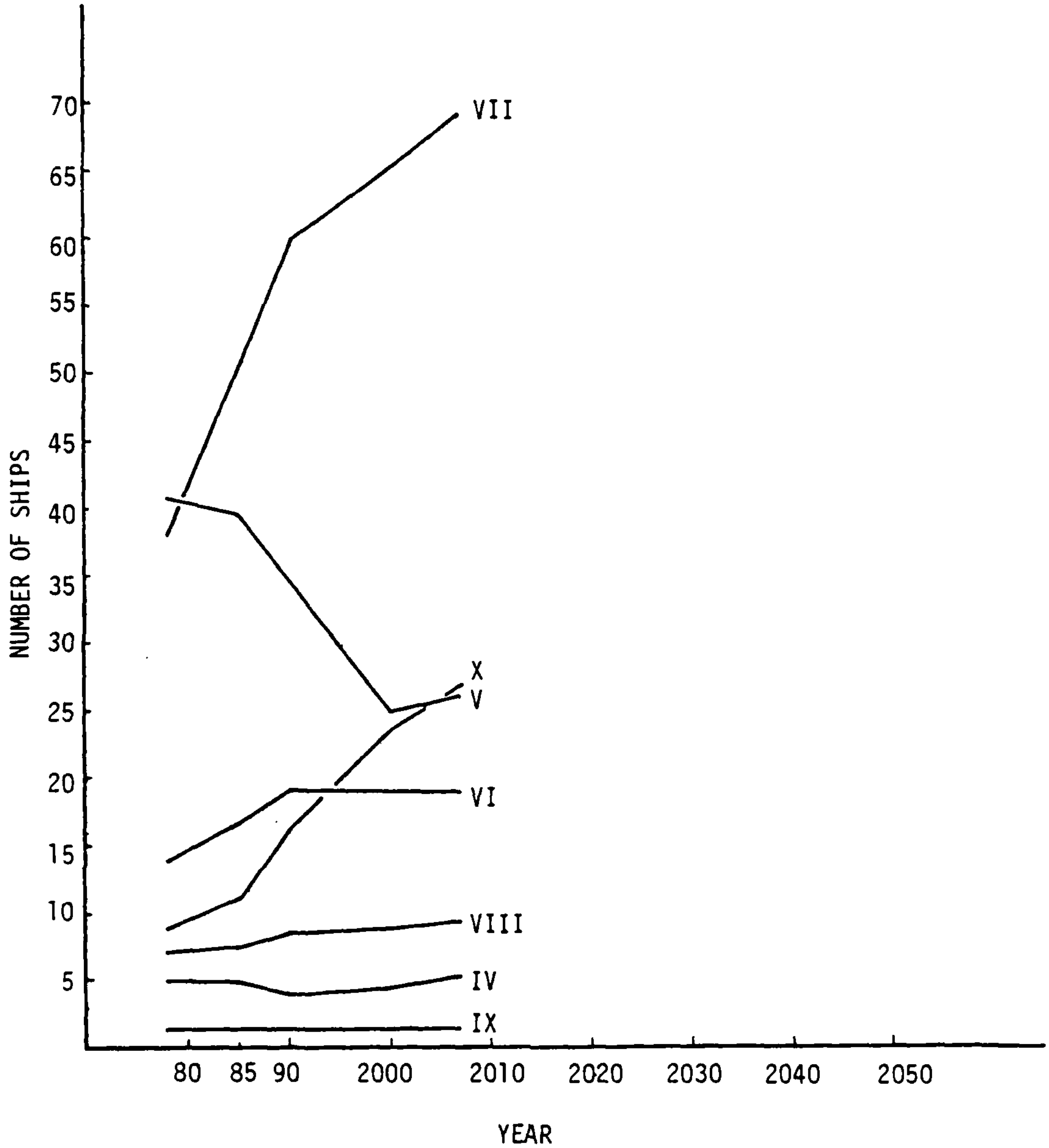


FIGURE 5.9 BASELINE FLEET MIX FOR SOO, 27 FOOT DRAFT

As capacity is approached, both average ship waiting time and average ship queue length increase exponentially at the constraining locks. Figure 5.10 shows lock utilization, average queue length, and average ship waiting time for the Poe Lock from 1978 to capacity in 2010. Figure 5.11 shows lock utilization, average queue length, and average ship waiting time for the MacArthur Locks from 1979 to capacity in 2010.

5.5.2.2 Welland Canal - The Welland Canal is the constraining lock system on the GL/SLS System. Based on an allowable ship draft of 26 feet and a capacity definition of 90% lock utilization, capacity at the Welland Canal will be reached in 1984. The tonnage processed through the Welland Canal at capacity is expected to be 78,926,000 short tons.

The 1984 capacity tonnage of 78,926,000 short tons is an increase of 10,862,000 short tons, or 16.0%, over the 68,064,000 short tons processed through the Welland Canal in 1978. The increased tonnage is mainly the result of a 74.5% increase in general cargo and a 17.4% increase in grain.

To accommodate these increases, the fleet operating through the Welland Canal increased 14.7%, from 113.6 ships in 1978 to 130.3 ships in 1984. The composite ship class increased from 5.9 in 1978 to 6.0 in 1984. Only a few small ships could be retired in that time, resulting in only a slight capacity gain due to increased ship size. The Welland Canal fleet mix from 1978 to the year capacity is reached is shown in Figure 5.12.

The total number of transits through the Welland Canal increased from 6,395 in 1978 to 7,024 in 1984, for a change of 9.8%. More significantly, the percentage of loaded transits increased from 63.1% of total transits in 1978 to 65.2% in 1984 because of a more even distribution of the upbound and downbound tonnages. The increase in this percentage increased the system capacity at no cost. The number of transits through the Welland Canal averaged over 31 per day during the period from May through November 1984.

Capacity was reached at the constraining lock on the Welland Canal in 1984 at an average lock utilization of 90.1% during the peak months of May through November. During the period of heaviest traffic in July, the lock utilization was 96%. The average waiting time was 16.0 hours upbound and 8.9 hours downbound. The average queue length was 10.6 ships upbound and 5.9 ships downbound. Lock utilization, vessel queue length, and average waiting time are shown on Figure 5.13.

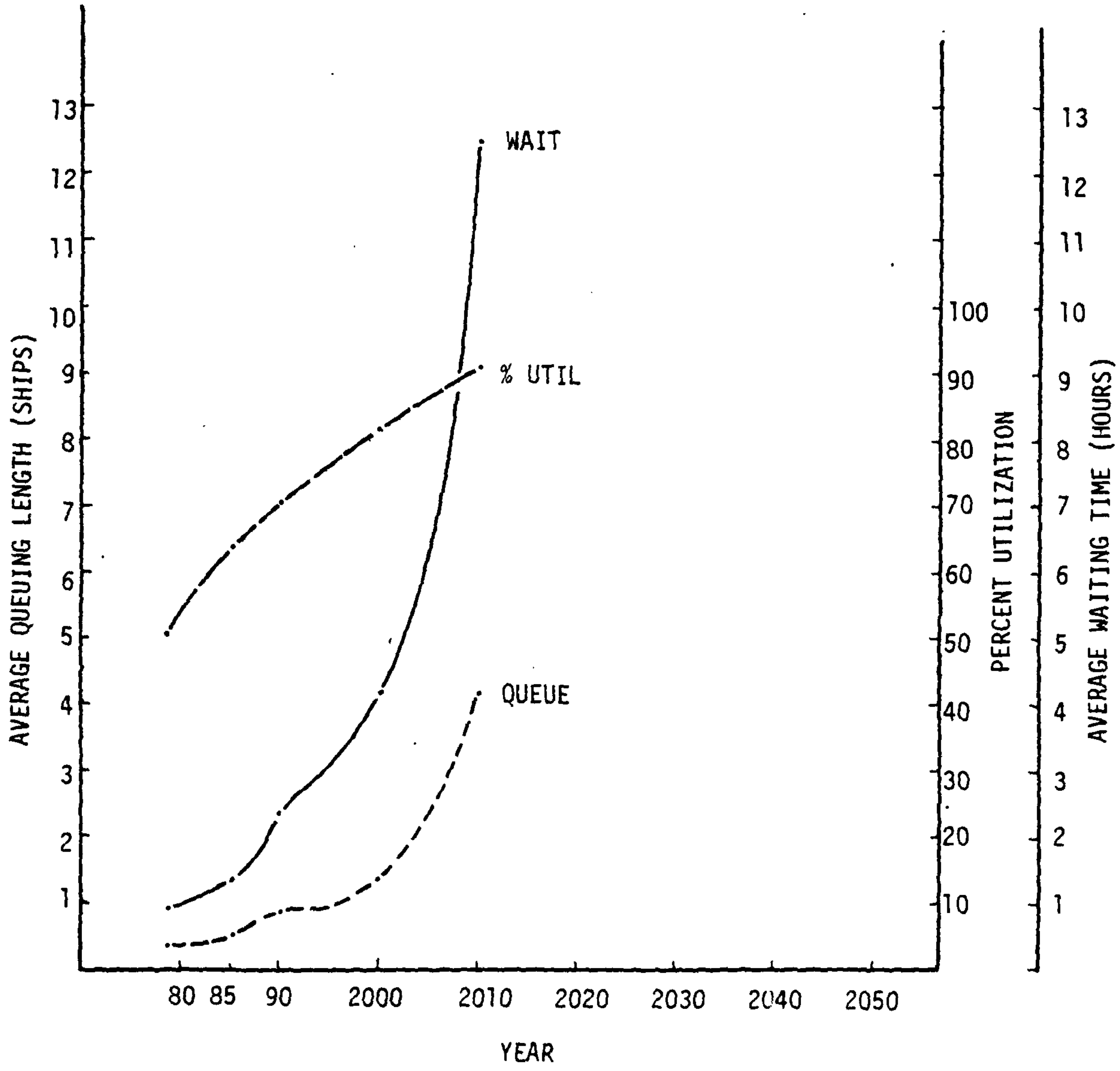


FIGURE 5.10 BASELINE QUEUE LENGTH, WAITING TIME, AND % UTILIZATION, POE LOCK, 27 FOOT DRAFT

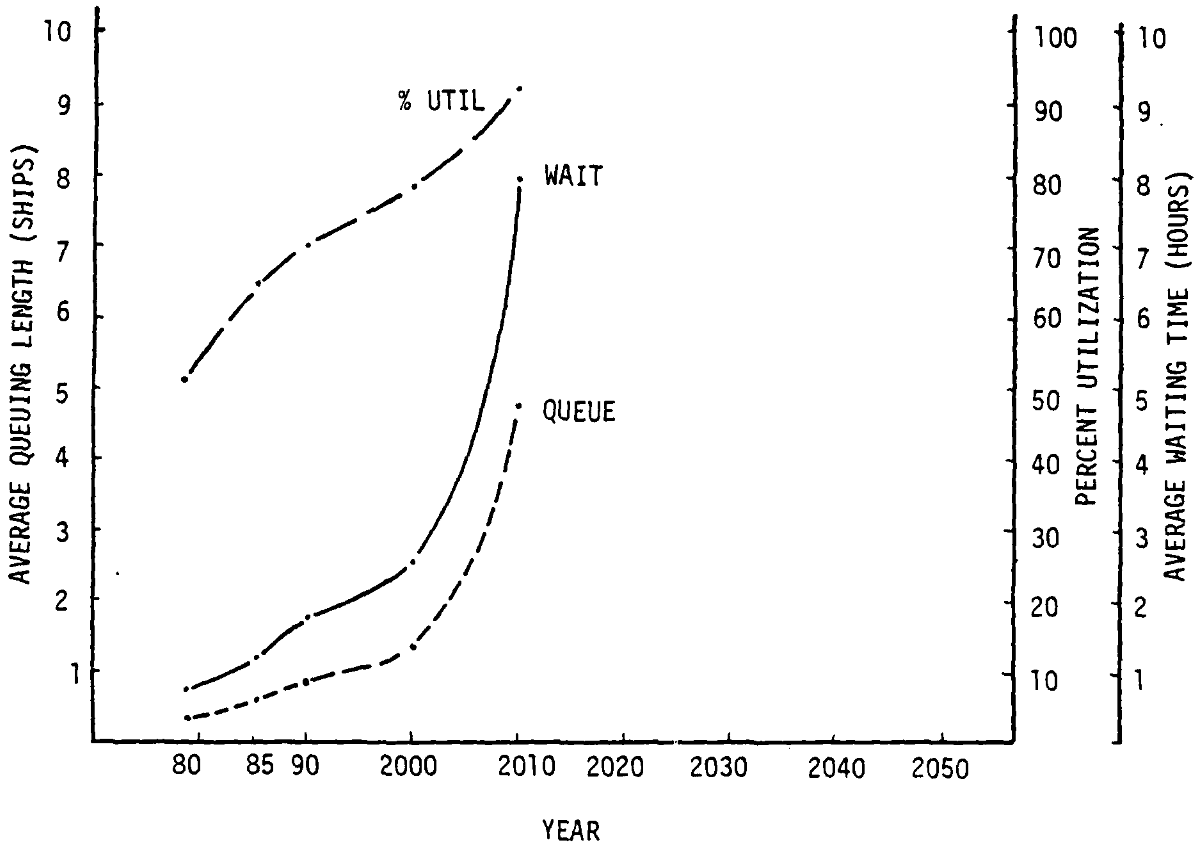


FIGURE 5.11 BASELINE QUEUE LENGTH, WAITING TIME, AND % UTILIZATION, MacARTHUR LOCK, 27 FOOT DRAFT

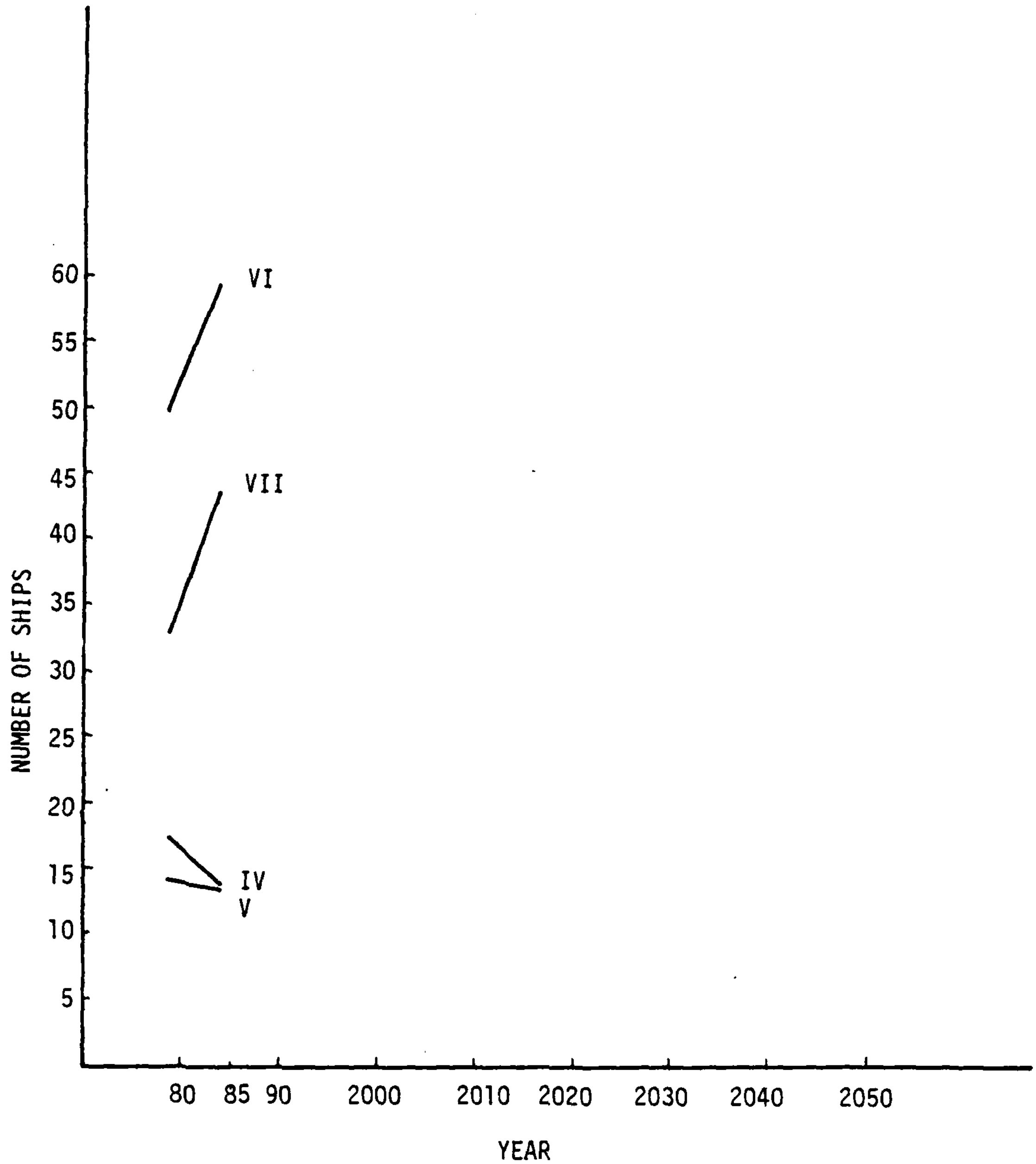


FIGURE 5.12 BASELINE FLEET MIX FOR WELLAND CANAL,
26 FOOT DRAFT

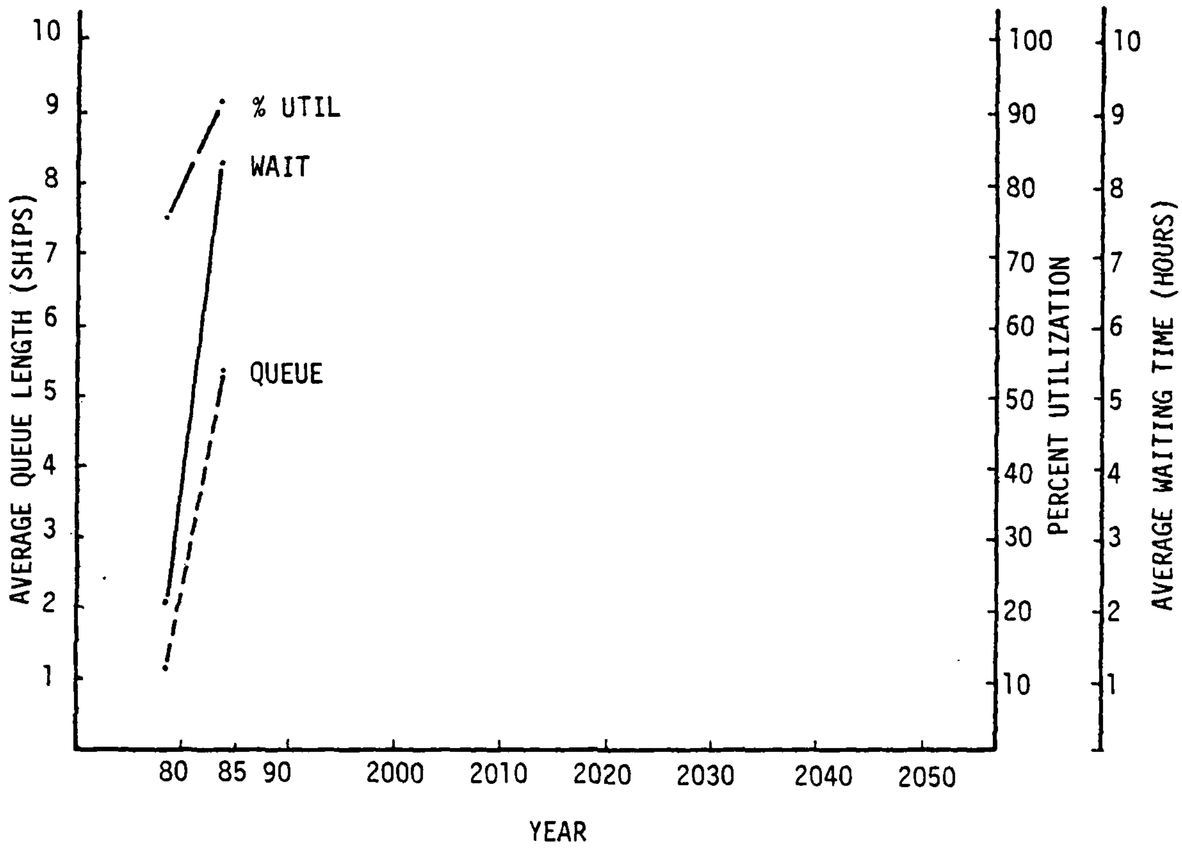


FIGURE 5.13 BASELINE QUEUE LENGTH, WAITING TIME, AND % UTILIZATION, WELLAND CANAL; 26 FOOT DRAFT

5.5.2.3 St. Lawrence River - Based on the input data and a capacity definition of 90% lock utilization, the St. Lawrence River Locks are expected to reach capacity in the year 2014. This assumes that water levels will remain at their present high levels, allowing ship drafts up to 26 feet. An estimated 99,174,000 short tons will pass through the St. Lawrence River Locks at capacity.

The capacity tonnage of 99,174,000 short tons in 2014 is an increase of 34,958,000 short tons or 54.4% over the 64,216,000 short tons processed through the St. Lawrence River Locks in 1978. The most significant increases in tonnage came from grain, increasing 50.9%, and general cargo increasing 98.9%.

The St. Lawrence River fleet increased from 109.0 ships in 1978 to 156.3 ships in 2014, a change of 43.4%. The composite ship class increased from 5.7 to 6.1 showing an increase in overall capacity due to the trend toward larger ships. More significantly, the composite grain ship increased from 5.9 in 1978 to 6.6 in 2014. The St. Lawrence River fleet mix from 1978 to capacity in 2014 is shown on Figure 5.14.

The total number of transits through the St. Lawrence River increased from 40.0% from 5,663 in 1978 to 7,930 in 2014. The percentage of loaded to total transits increased from 68.0% in 1978 to 69.9% in 2014 due to a more even distribution of upbound and downbound cargos. This, and the increase in fleet size, resulted in an increase in capacity at no cost.

Capacity was reached at the St. Lawrence River Locks with an average lock utilization at the constraining lock of 90.4% during the peak months of May through November. During the heaviest traffic in July, the lock utilization was greater than 98% with an average waiting time of 27.6 hours upbound and 22.0 hours downbound, and an average queue length of 21.2 ships upbound and 16.9 ships downbound. Lock utilization, average queue length, and average waiting time for the constraining lock are shown on Figure 5.15.

5.5.3 Minimum Water Level Base Case - 25.5 Foot Draft

5.5.3.1 Soo Locks - Water levels are assumed to be at low water datum allowing ship drafts equal to 25.5 feet. Based on this condition and a capacity definition of 90% of lock utilization, the Soo Locks are expected to reach capacity in the year 2006. The tonnage processed through the Soo Locks at

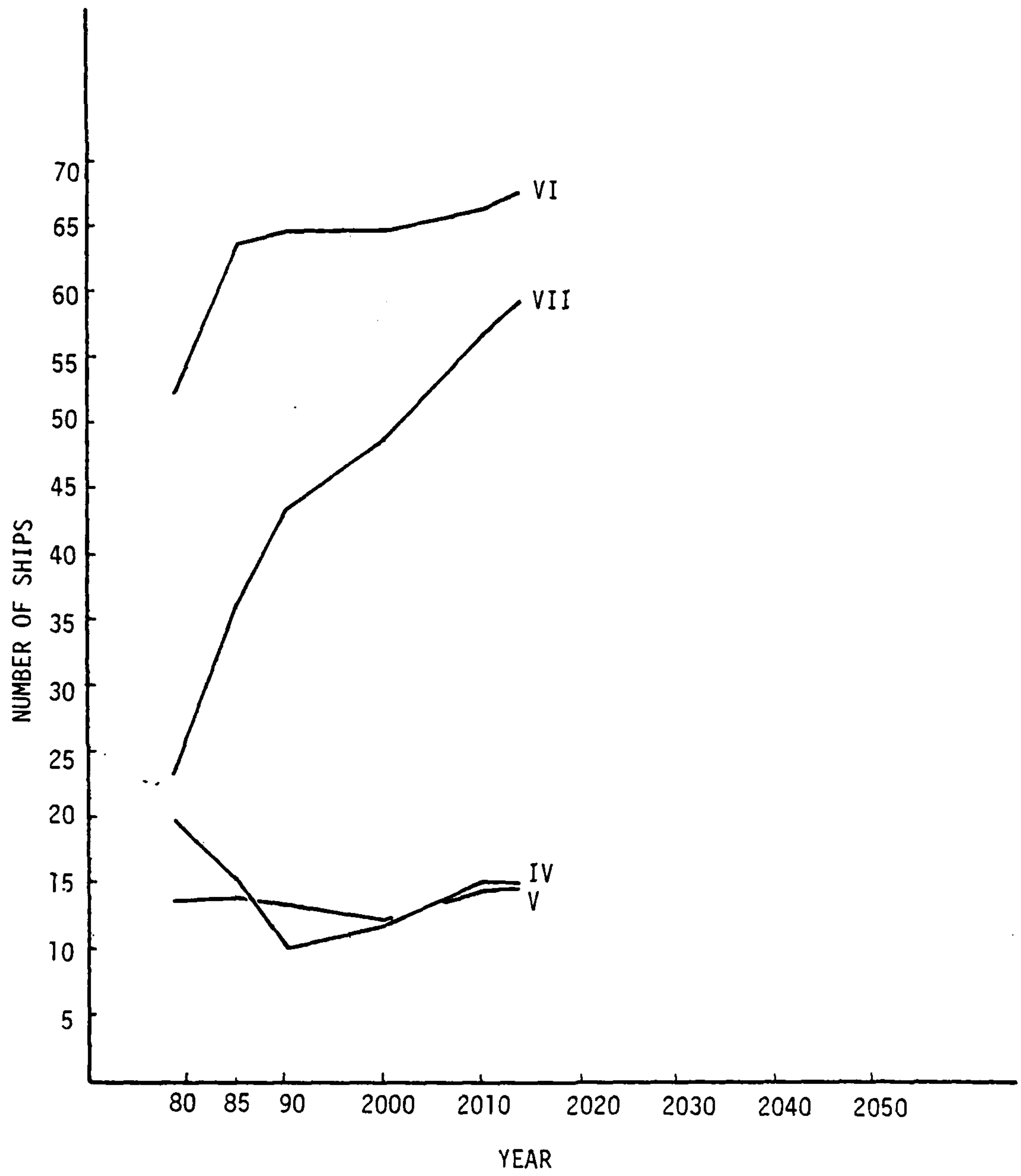


FIGURE 5.14 BASELINE FLEET MIX, ST. LAWRENCE RIVER, 26 FOOT DRAFT

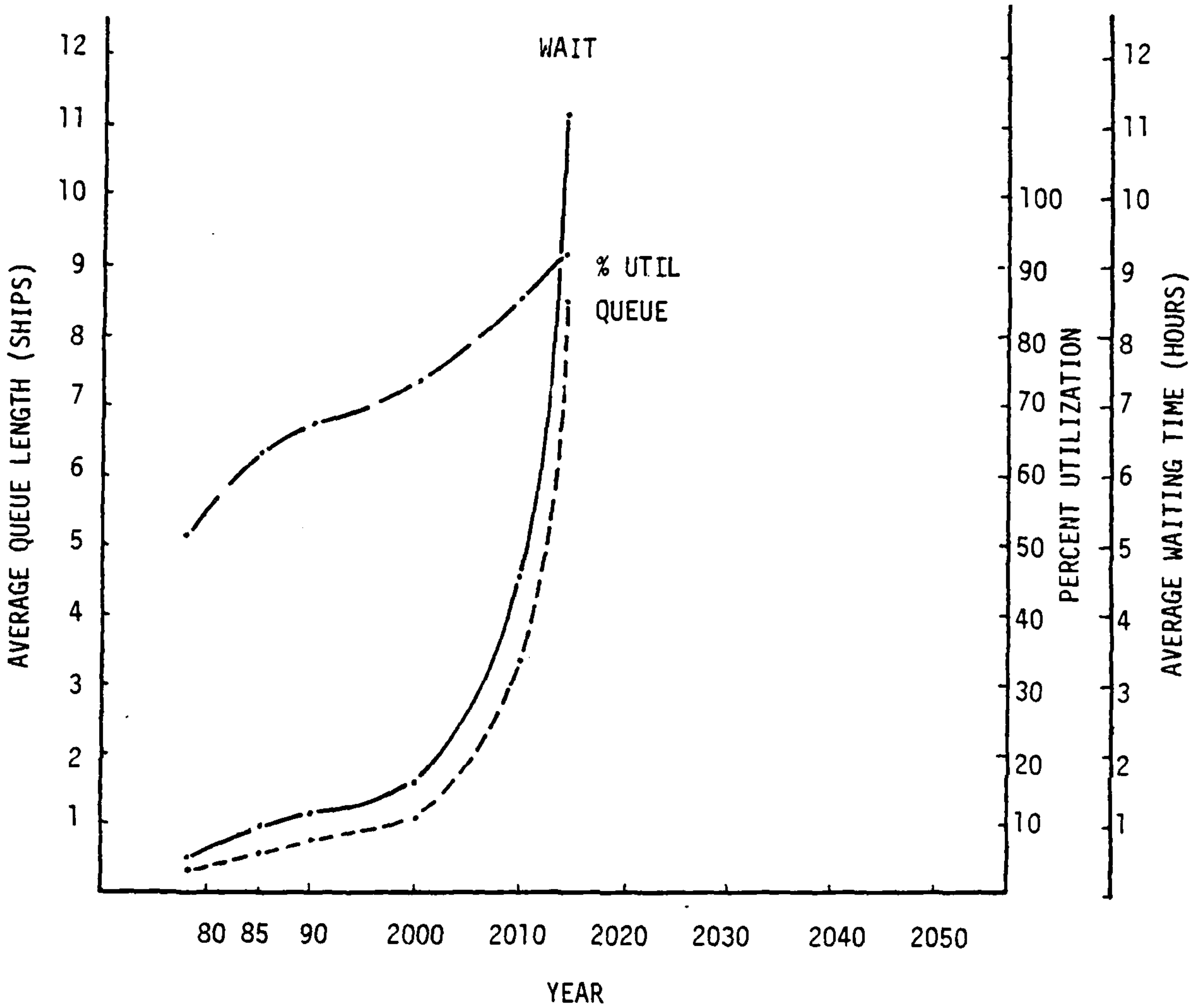


FIGURE 5.15 BASELINE QUEUE LENGTH, WAITING TIME, AND % UTILIZATION, ST. LAWRENCE RIVER; 26 FOOT DRAFT

capacity will be 173,739,000 short tons. This traffic load is an increase of 61.8% over the 107,390,000 short tons processed through the Soo Locks in 1978. Much of the increased tonnage came from coal, which increased 40%; grain, which increased 55.1%; and iron ore, which increased 45.8%.

The fleet operating through the Soo Locks increased 36.3%, from 113.2 ships in 1978 to 154.3 ships in 2006. At the same time, the composite ship class increased from 6.3 to 7.0 which resulted in an increase in capacity of the locks. Most of the increase in composite ship size came from iron ore and coal. The composite iron ore ship class increased from 6.8 in 1978 to 8.3 in 2006. The composite coal ship class increased from 6.0 in 1978 to 7.7 in 2006. The Soo fleet mix from 1978 to 2006 is shown on Figure 5.16.

The total number of transits through the Soo Locks increased 33.7%, from 8,099 in 1978 to 10,825 in 2006. At the same time, the percentage of loaded transits decreased from 56.2% in 1978 to 55.7% in 2006 as the downbound cargos increased at a faster rate than the upbound cargos. This decrease resulted in a slight loss of capacity.

Lock utilization at capacity during the peak demand months of May through November averaged 92.0% at the Poe Lock and 92.1% at the MacArthur Lock. During the period of heaviest traffic in July, utilization at the Poe Lock was 92%, the average vessel waiting time was 3.1 hours upbound and 15.9 hours downbound, and the average queue length was 0.7 vessels upbound and 5.4 vessels downbound. During the most severe month at the MacArthur Lock, May, the lock utilization was 93%, average vessel waiting time was 0.3 hours upbound and 9.5 hours downbound, and the average queue length was 0.03 ships upbound and 5.8 ships downbound. Lock utilization, average vessel waiting time, and average queue length are shown on Figure 5.17 for the Poe Lock and on Figure 5.18 for the MacArthur Lock.

The Sabin and Davis Locks are non-constraining locks at the Soo. In 2006, when both the Poe and the MacArthur were at capacity, the Sabin Lock averaged 49% utilization during the peak period. The Davis Lock was not in use.

5.5.3.2 Welland Canal - At the guaranteed system-wide draft of 25.5 feet and a capacity definition of 90% lock utilization, the Welland Canal is expected to reach capacity in 1981. The Welland is not actually at capacity now because high water is permitting deeper draft requiring less transits to

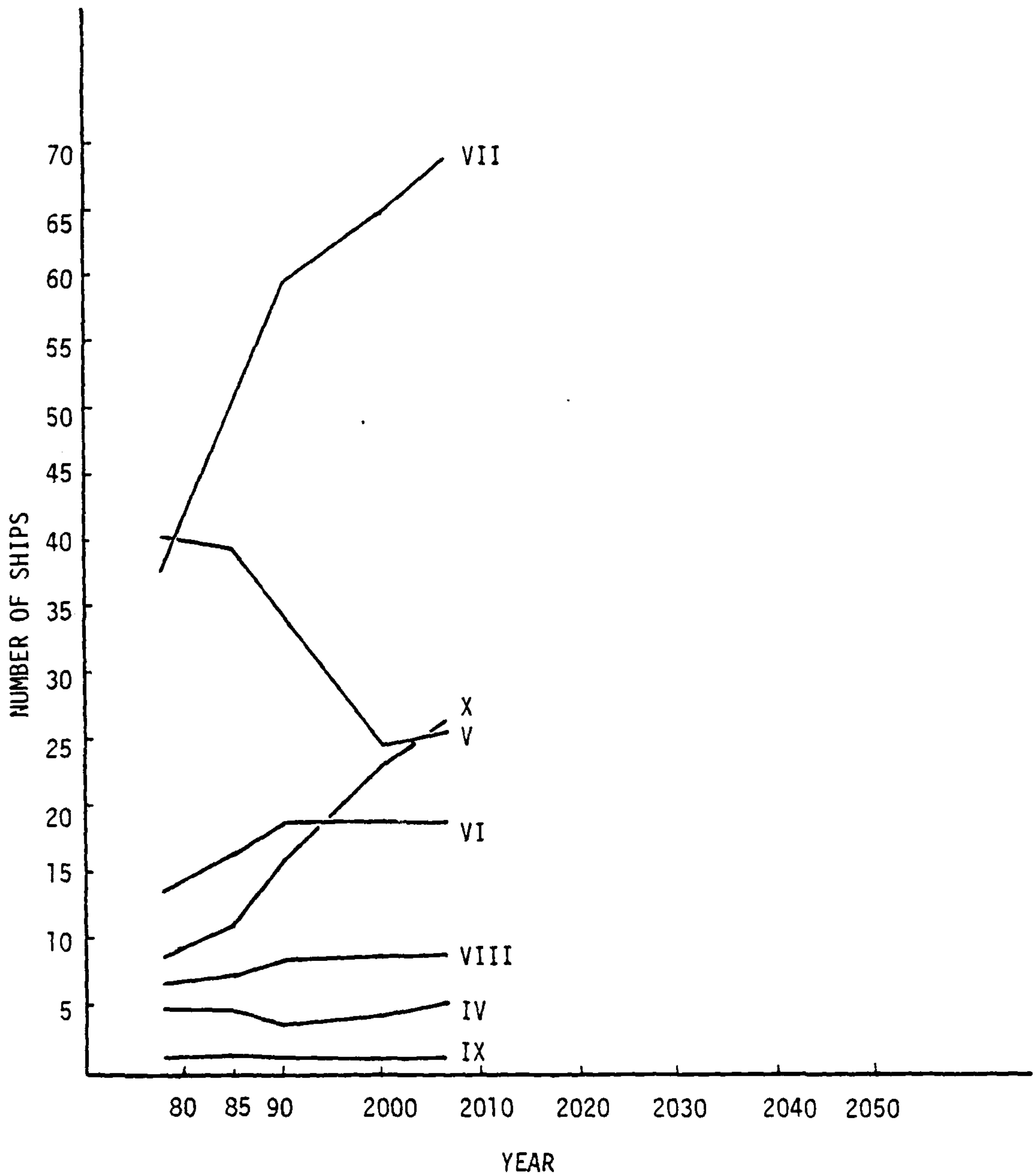


FIGURE 5.16 BASELINE FLEET MIX FOR SOO, 25.5 FOOT DRAFT

AD-A111 069 ARCTEC INC COLUMBIA MD F/G 13/2
GREAT LAKES/ST. LAWRENCE SEAWAY REGIONAL TRANSPORTATION STUDIES--ETC(U)
SEP 81 A P FREE, M R HORNE, R H SCHULZE DACW35-80-C-0060
UNCLASSIFIED 719C-6 NL

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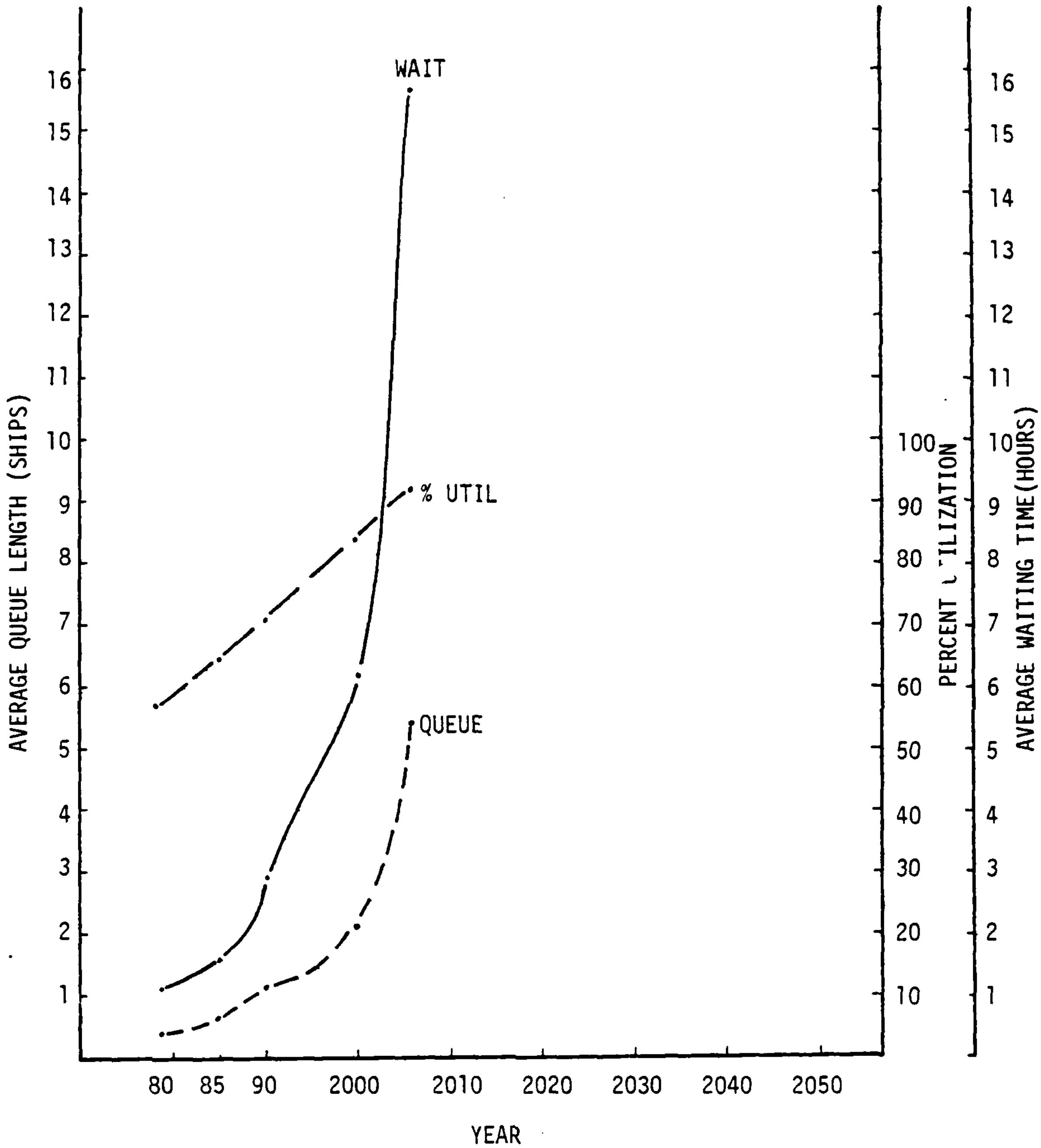

FIGURE 5.17 BASELINE QUEUE LENGTH, WAITING TIME, AND % UTILIZATION, POE LOCK; 25.5 FOOT DRAFT

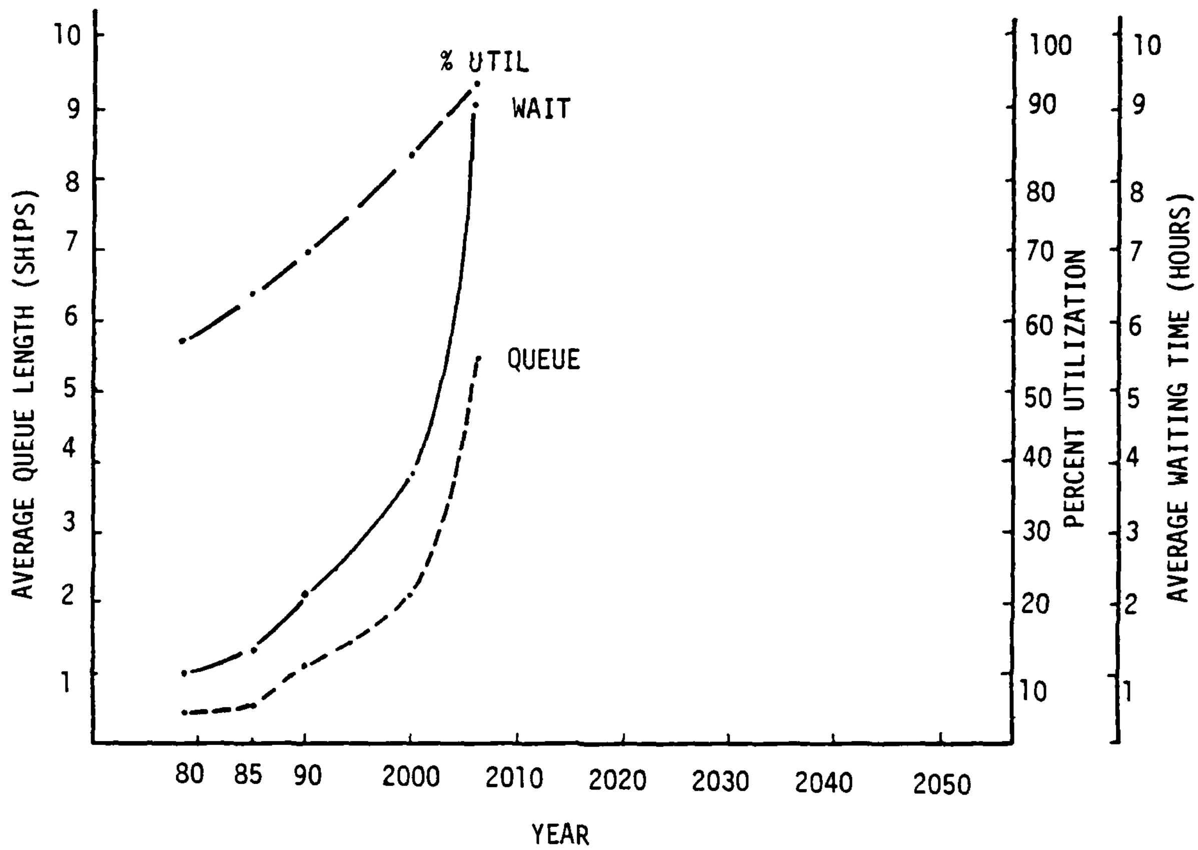

FIGURE 5.18 BASELINE QUEUE LENGTH, WAITING TIME, AND % UTILIZATION, MacARTHUR LOCK; 25.5 FOOT DRAFT

process the same amount of cargo. The amount of cargo processed through the Welland Canal at capacity will be 75,187,000 short tons.

The capacity tonnage at the Welland Canal of 75,198,000 short tons is an increase of 7,131,000 short tons or 10.5% over the 68,067,000 short tons processed in 1978. The major increases in cargo came from general cargo which increased 49.1%, and grain which increased 11.6%.

The number of ships utilizing the Welland Canal increased 9.1% from 119.5 ships in 1978 to 130.4 ships in 1981. At the same time the composite ship class increased from 5.9 to 6.0 providing a slight increase in capacity due to the larger sized fleet. The Welland fleet mix from 1978 to capacity is shown on Figure 5.19.

The total number of transits through the Welland Canal increased 5.9% from 6,865 in 1978 to 7,268 in 1981. The percentage of loaded transits increased from 63.2% in 1978 to 64.7% in 1981, allowing for a small capacity increase. The number of transits through the Welland Canal averaged over 31 per day during the months of May through November 1981.

At capacity, the constraining lock at the Welland Canal averaged 94.4% lock utilization for the peak period from May to November. During the period of highest traffic in July, lock utilization was greater than 98%, average vessel waiting time was 36.0 hours upbound and 35.4 hours downbound, and average queue length was 24.2 ships upbound and 24.2 ships downbound. Lock utilization, average vessel waiting time, and vessel queue length are shown on Figure 5.20.

5.5.3.3 St. Lawrence River - Based on the definition of lock capacity as 90% lock utilization and a operating draft of 25.5 feet, the St. Lawrence River will reach capacity in the year 2006. At capacity the amount of cargo passing through the St. Lawrence River Locks will be 92,526,000 short tons.

The capacity tonnage of 92,526,000 is an increase of 44.1% or 28,313,000 short tons over the 64,213,000 short tons processed in 1978. The major cargo increases came in general cargo, other bulk, iron ore, and grain. General cargo increased 90.8%, other bulk increased 42.7%, grain increased 41.8%, and iron ore increased 30.2%.

The number of ships operating through the St. Lawrence River Locks increased from 114.3 in 1978 to 152.8 ships in 2006

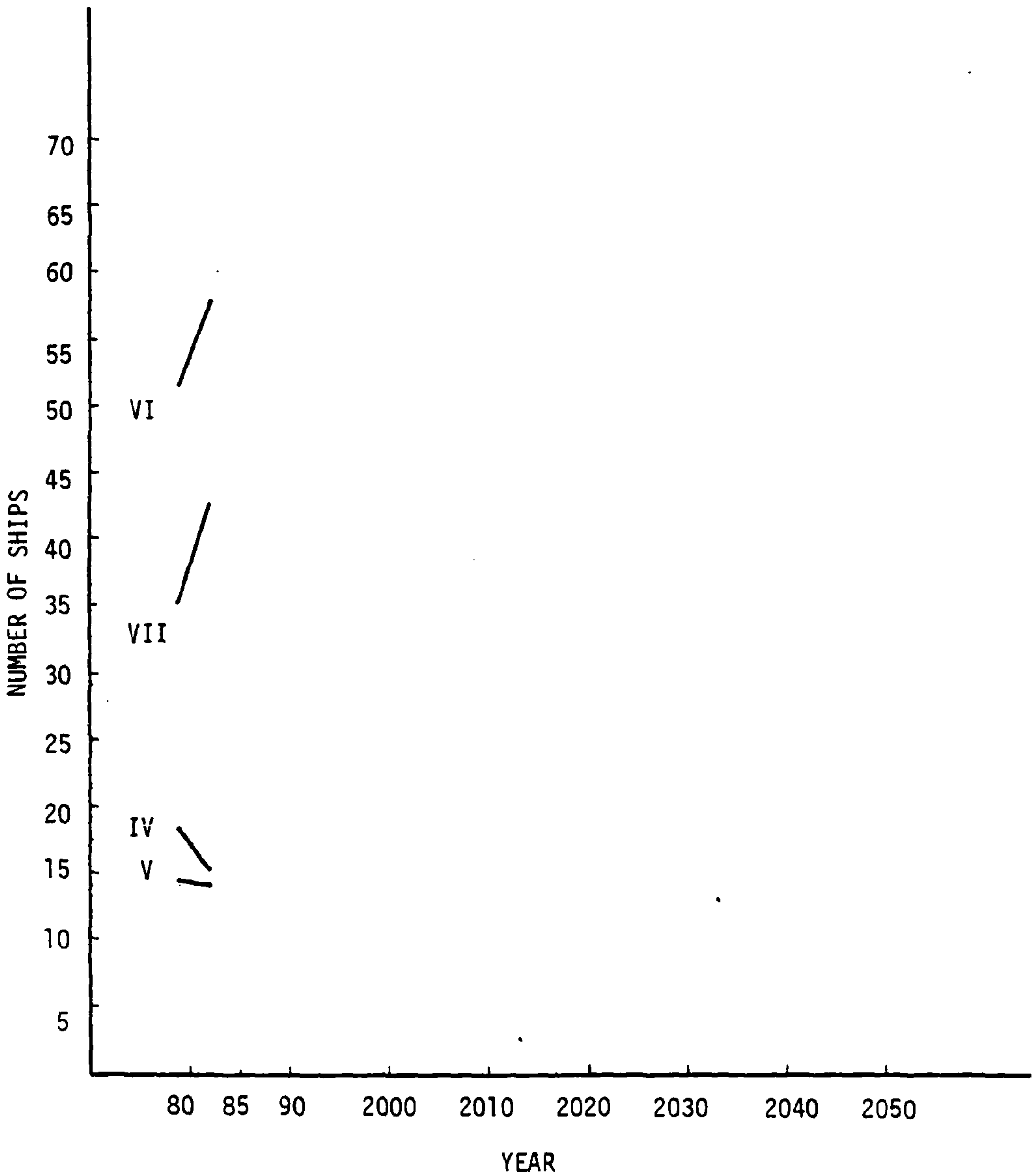

FIGURE 5.19 BASELINE FLEET MIX FOR WELLAND CANAL, 25.5 FOOT DRAFT

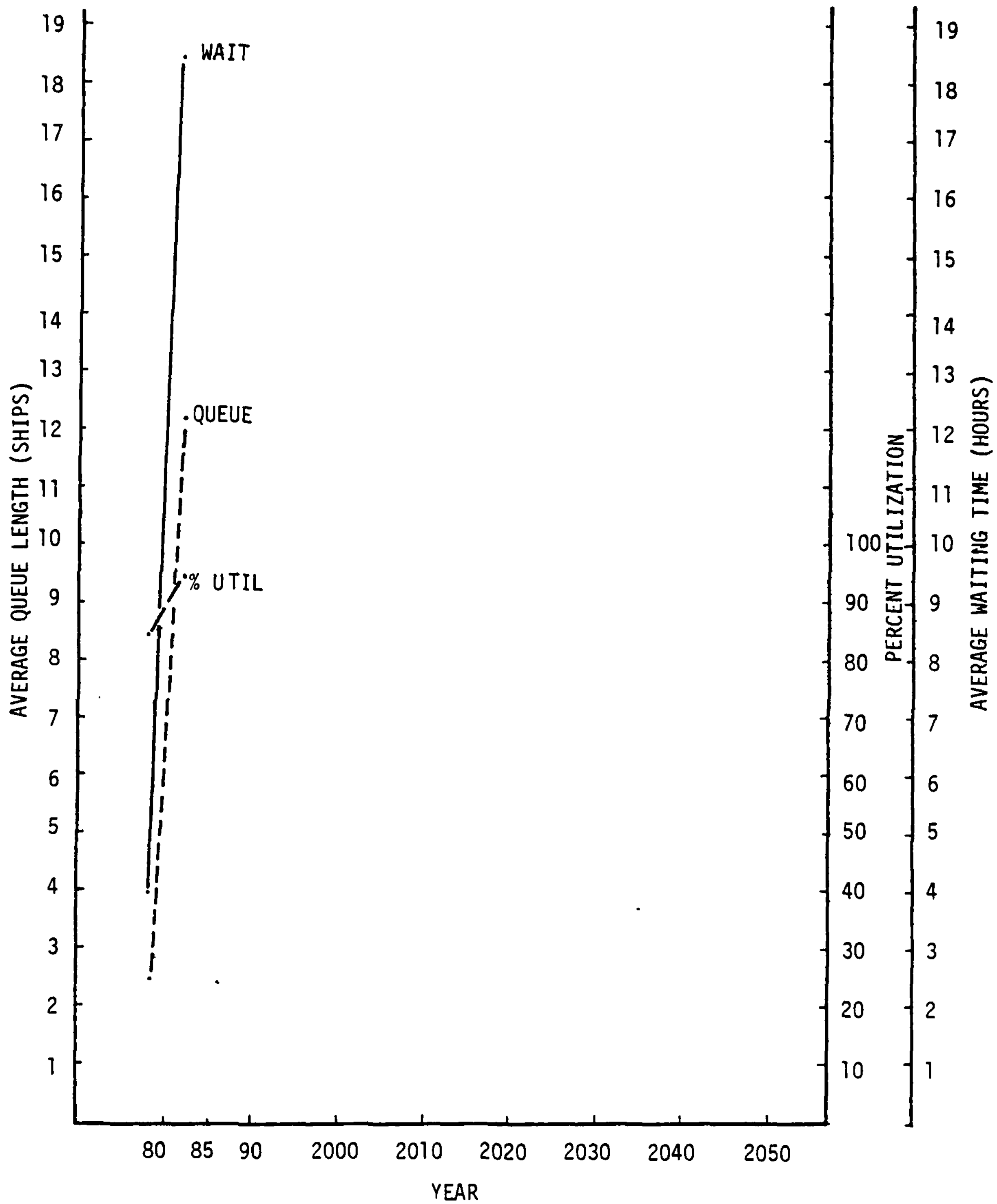

FIGURE 5.20 BASELINE QUEUE LENGTH, WAITING TIME, AND % UTILIZATION, WELLAND CANAL; 25.5 FOOT DRAFT

for a percent increase of 33.7%. During this time, the composite ship class rose from 5.7 in 1978 to 6.1 in 2006, resulting in an increase in system capacity due to increased tonnage per lockage. Much of this increase is the result of increases in the composite size of ore, coal, and grain ships. The composite ore ship increased from 6.1 in 1978 to 6.7 in 2006. The composite coal ship increased from 6.0 in 1978 to 6.8 in 2006. The composite grain ship increased from 5.9 in 1978 to 6.5 in 2006. The fleet mix for the St. Lawrence River from 1978 to capacity in 2006 is shown on Figure 5.21.

The total number of transits through the St. Lawrence River increased 29.9% from 6,091 in 1978 to 7,910 in 2006. At the same time the percent loaded transits increased from 67.5% in 1978 to 70.0% in 2006. This was due to a more equal distribution of upbound and downbound cargos and resulted in a small increase in capacity.

At capacity in 2006, the constraining lock on the St. Lawrence River had an average lock utilization of 90.1% over the peak months of May through November. During July, the most severe month, the lock utilization was 97%, the average vessel waiting time was 24.8 hours upbound and 20.0 hours downbound, and the average queue length was 19.1 ships upbound and 15.3 ships downbound. Lock utilization, average vessel waiting time, and vessel queue length are shown on Figure 5.22.

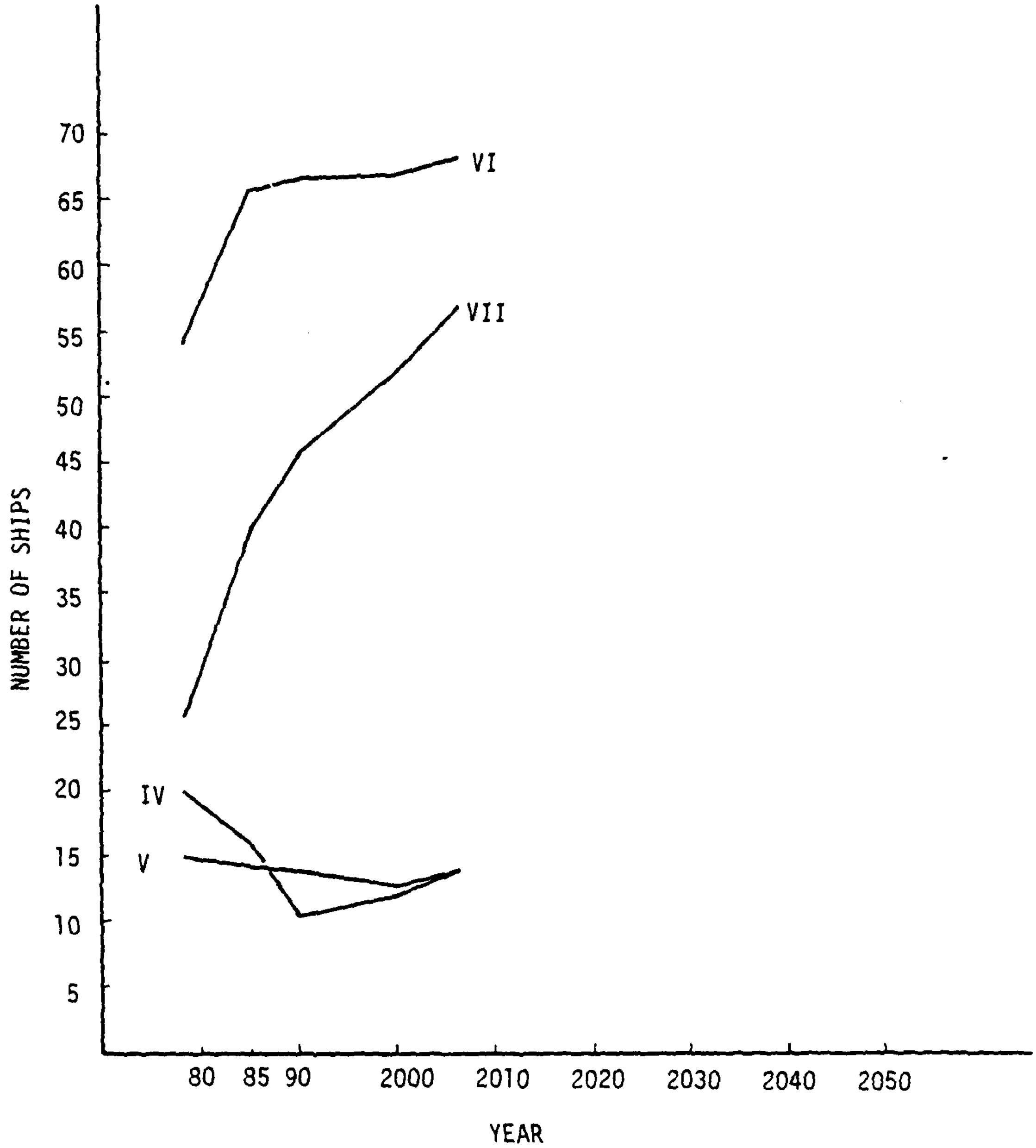

FIGURE 5.21 BASELINE FLEET MIX FOR ST. LAWRENCE RIVER, 25.5 FOOT DRAFT

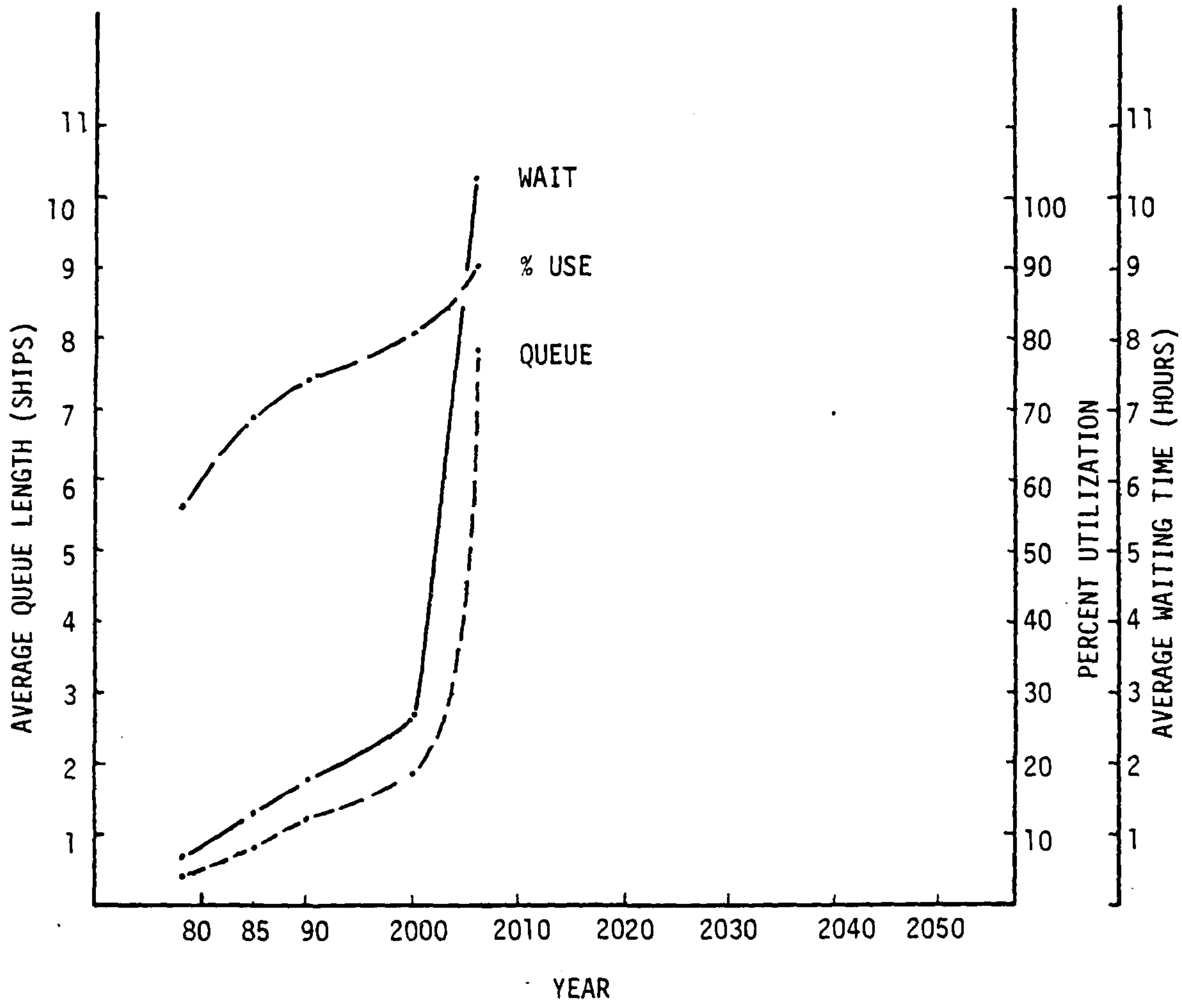

FIGURE 5.22 BASELINE QUEUE LENGTH, WAITING TIME, AND % UTILIZATION, ST. LAWRENCE RIVER; 25.5 FOOT DRAFT

6. ANALYSIS OF NON-STRUCTURAL ALTERNATIVES

6.1 Introduction

Non-structural capacity expansion alternatives are a means of increasing the tonnage processed through a lock system without constructing new locks or performing major structural lock and channel modifications. The non-structural alternatives increase lock capacity by changing a component of the locking system. In this study all of the non-structural alternatives selected for consideration by the Corps of Engineers have the effect of reducing locking time. Other non-structural alternatives might increase capacity by maximizing the tonnage processed per lockage or by increasing the available lock operating time. Policy decisions resulting in preferential treatment, such as discouraging non-cargo carrying ships, are also considered non-structural alternatives. The Corps of Engineers did not select any alternatives of this type for inclusion in the study.

The Corps of Engineers selected four non-structural alternatives [8] for testing in this sensitivity and feasibility analysis. These alternatives are:

(1) Install Traveling Kevels

(2) Increase Ship Speed into Locks

(3) Decrease Chambering Time

(4) Install Lock Traffic Control Systems.

Each of these alternatives increase the capacity of a lock system by reducing a component of the locking time. A range of possible locking time reductions was established for each of the non-structural alternatives based on operational experience [9]. Engineering judgement was then used to determine a reasonable locking time reduction that could be obtained within this range. These most probable, or expected values, for the locking time reductions were then used in the analysis.

Each of the four non-structural alternatives are described in greater detail in the following sections of the report, along with the results of the sensitivity and feasibility analysis which determine the possible effect of each alternative on capacity. In addition to evaluating each

non-structural alternative alone, a non-structural improvement to maximum utility alternative was tested. This fifth non-structural alternative combines, as much as possible, the first four non-structural alternatives in a way that provides the maximum locking time reduction that can reasonably be expected from these alternatives. The results of the non-structural maximum utility alternative provides a base line of non-structural improvements against which the structural alternatives, discussed later in this report, are evaluated.

Although five specific non-structural alternatives are examined in this analysis, the capacity simulation results from these analyses may also be applied in other cases. For example, if a non-structural alternative not specified here were thought to be able to reduce locking times by 7.5%, the results of the traveling kevels capacity simulation could be used to evaluate this new alternative because the output would be the same. In general, therefore, these non-structural capacity simulations can be thought of as a locking time reduction sensitivity analysis against which any alternative for reducing locking time may be evaluated. Table 6.1 summarizes the five non-structural alternatives tested and their corresponding locking time reductions. The alternatives are discussed in the following sections of the report.

6.2 Traveling Kevels

6.2.1 Lock Improvement

Traveling kevels are wheeled movable mooring posts which would travel on a rail along the guide walls on both sides of the lock. Upon approaching the lock entrance, a ship would be moored to the kevels. The kevels would then tow the ship into the lock.

A ship under its own power must proceed into a lock very slowly to minimize the chance of damaging the lock or the ship. Using traveling kevels it is estimated that a ship would be able to move into the lock faster with the same degree of safety. Ship speed entering the lock would increase, decreasing locking time, although some of the time gain would be lost in hook-up and release from the assisting devices.

Traveling kevels would reduce the lockage time component of lock entry time which is approximately 15% of the total locking time. The best estimate of performance for traveling

TABLE 6.1 LOCKING TIME REDUCTIONS ASSOCIATED WITH THE NON-STRUCTURAL ALTERNATIVES

Non-Structural Alternative	SOO Upbound (%)	SOO Downbound (%)	WELLAND CANAL Upbound (%)	WELLAND CANAL Downbound (%)	ST. LAWRENCE RIVER Upbound (%)	ST. LAWRENCE RIVER Downbound (%)
Install Traveling Kevels	7.5	7.5	7.5	7.5	7.5	7.5
Increase Ship Speed into Lock	2.5	2.5	5.0	5.0	2.5	2.5
Reduce Chambering Time	1.0	5.5	2.5	5.0	1.0	5.5
Install Traffic Control System	4.5	4.5	3.0	3.0	4.5	4.5
Non-Structural to Maximum Utility Consisting of:						
Traveling Kevels, Reduce Dump/Fill Time, Traffic Control System	13.0	13.0	13.0	13.0	13.0	13.0

kevels is a reduction of entry time by approximately one-half resulting in a total locking time reduction of 7.5%. To evaluate the impact of this change, the Lock Capacity Model was run until it reached capacity using baseline data, then all of the locking times were reduced by 7.5% and the simulation was continued. The resulting delay in the year capacity was reached showed the benefit of installing traveling kevels.

6.2.2 Results of Capacity Simulation Using Traveling Kevels

6.2.2.1 Soo Locks - After the Soo Locks reached capacity in 2006, traveling kevels were installed and the capacity condition was delayed until 2014. At this new capacity level the Soo Locks processed 189,501,000 short tons of cargo. This is an increase of 15,762,000 short tons or 9.1% over the 173,739,000 short tons that passed through the lock in 2006.

Most of the increases in cargo between 2006 and 2014 came in iron ore and grain. Iron ore increased 11.4% while grain increased 6.2%.

The number of vessels in the Soo Locks fleet increased 6.1%, from 154.3 ships in 2006 to 164.6 ships in 2014. The composite ship class for the Soo fleet increased only slightly from 7.0 in 2006 to 7.1 in 2014. Therefore, very little capacity was gained due to growth in the size of the Soo fleet. The Soo fleet mix from 1978 to 2014 is shown on Figure 6.1.

The total number of transits through the Soo Locks increased 6.4%, from 10,825 transits in 2006 to 11,517 transits in 2014. The percentage of loaded transits remained fairly constant, increasing slightly from 55.7% in 2006 to 55.9% in 2014. Reduction of ballasted lockages therefore had little effect in increasing the Soo capacity from 2006 to 2014.

Capacity at the Soo was reached at the Poe and MacArthur Locks in 2014. The Poe and MacArthur Locks each had average lock utilizations during the peak months of May through November of 92.0%. During October, the month of heaviest traffic at the Poe Lock, the lock utilization was 92.0%, the average vessel waiting time was 3.7 hours upbound and 15.9 hours downbound, and the average queue length was 1.0 ships upbound and 5.6 ships downbound. Lock utilization, average vessel waiting time, and average queue length for the Poe Lock are shown on Figure 6.2. During May, the most severe month at the MacArthur Lock, utilization was 92.0%, average vessel waiting time was 0.3 hours upbound and 8.7 hours downbound, and average queue

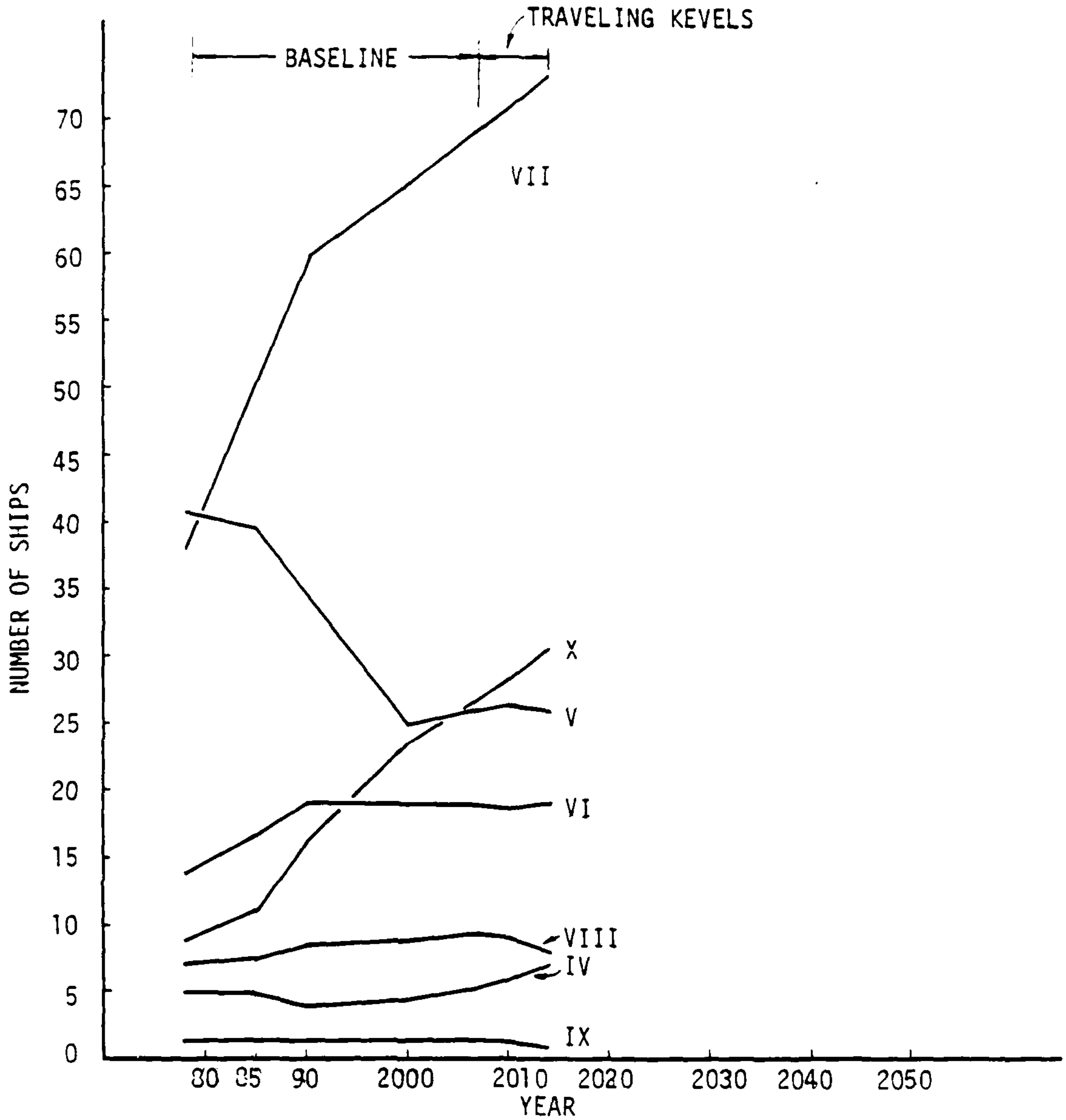

FIGURE 6.1 SOO FLEET MIX - TRAVELING KEVELS

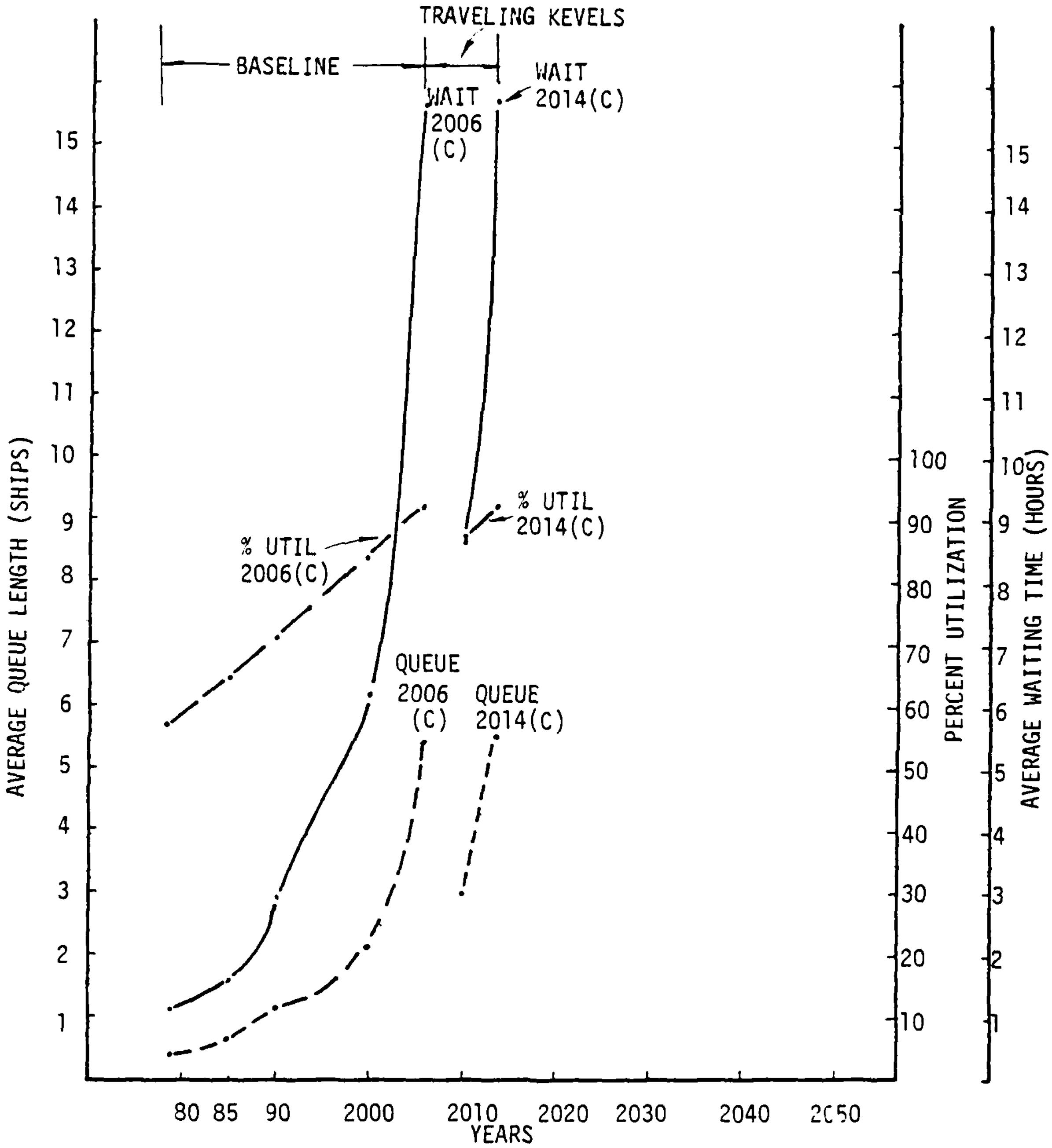

FIGURE 6.2 TRAVELING KEVELS POE LOCK, QUEUE LENGTH, WAITING TIME, % UTILIZATION, 25.5 FOOT DRAFT

length was 0.03 ships upbound and 5.7 ships downbound. Lock utilization, average vessel waiting time, and average queue length for the MacArthur Lock are given on Figure 6.3.

6.2.2.2 Welland Canal - After adding traveling kevels when the original capacity condition was reached in 1981, the Welland Canal again reached capacity in 1985. At capacity in 1985 a total of 80,738,000 short tons of cargo were processed through the Welland Canal. This is an increase of 5,540,000 short tons, or 7.5%, over the 75,198,000 short tons of cargo processed through the locks in 1981.

The commodities that had the largest increases in cargo from 1981 to 1985 were general cargo and grain. General cargo increased 25.4%, and grain cargo increased 7.8%.

The number of ships in the Welland Canal fleet increased 6.7%, from 130.4 ships in 1981 to 139.1 ships in 1985. The composite ship class for the Welland Canal fleet remained constant at 6.0 from 1981 to 1985; therefore, capacity did not increase because of an increase in ship size. The Welland Canal fleet mix is shown on Figure 6.4.

The total number of transits through the Welland Canal increased 4.9%, from 7,268 transits in 1981 to 7,627 transits in 1985. A slight increase occurred in the percentage of loaded transits, from 64.7% in 1981 to 65.2% in 1985, which resulted in a small capacity increase.

Lock utilization at the constraining lock on the Welland Canal during the capacity year of 1985 was an average of 90.7% over the peak months of May through November. During July, the most severe month, the lock utilization was 96.0% and the average vessel waiting time was 16.5 hours upbound and 8.8 hours downbound. The lock utilization, average waiting time, and average queue length are shown in Figure 6.5.

6.2.2.3 St. Lawrence River - After installing traveling kevels at the final capacity level in 2006, capacity on the St. Lawrence River Locks was delayed until 2016. The cargo processed through the St. Lawrence Locks at capacity in 2016 was 100,534,000 short tons. This is an increase of 8,008,000 short tons or 8.7% over the base case capacity in 2006 of 92,526,000 short tons.

Most of the tonnage increase through the St. Lawrence River from 2006 to 2016 was in the categories of other bulk,

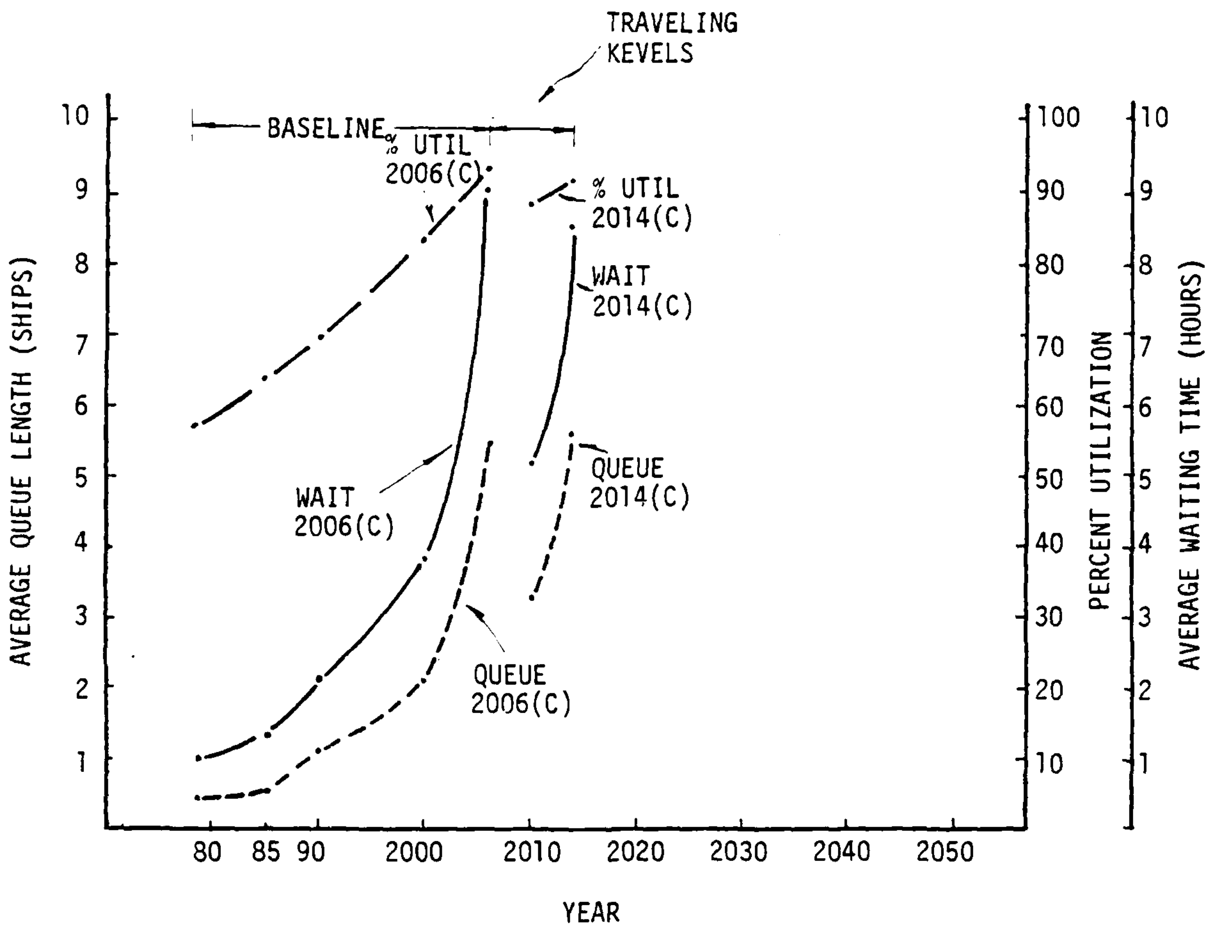

FIGURE 6.3 TRAVELING KEVELS, MacARTHUR LOCK, QUEUE LENGTH, WAITING TIME, % UTILIZATION; 25.5 FOOT DRAFT

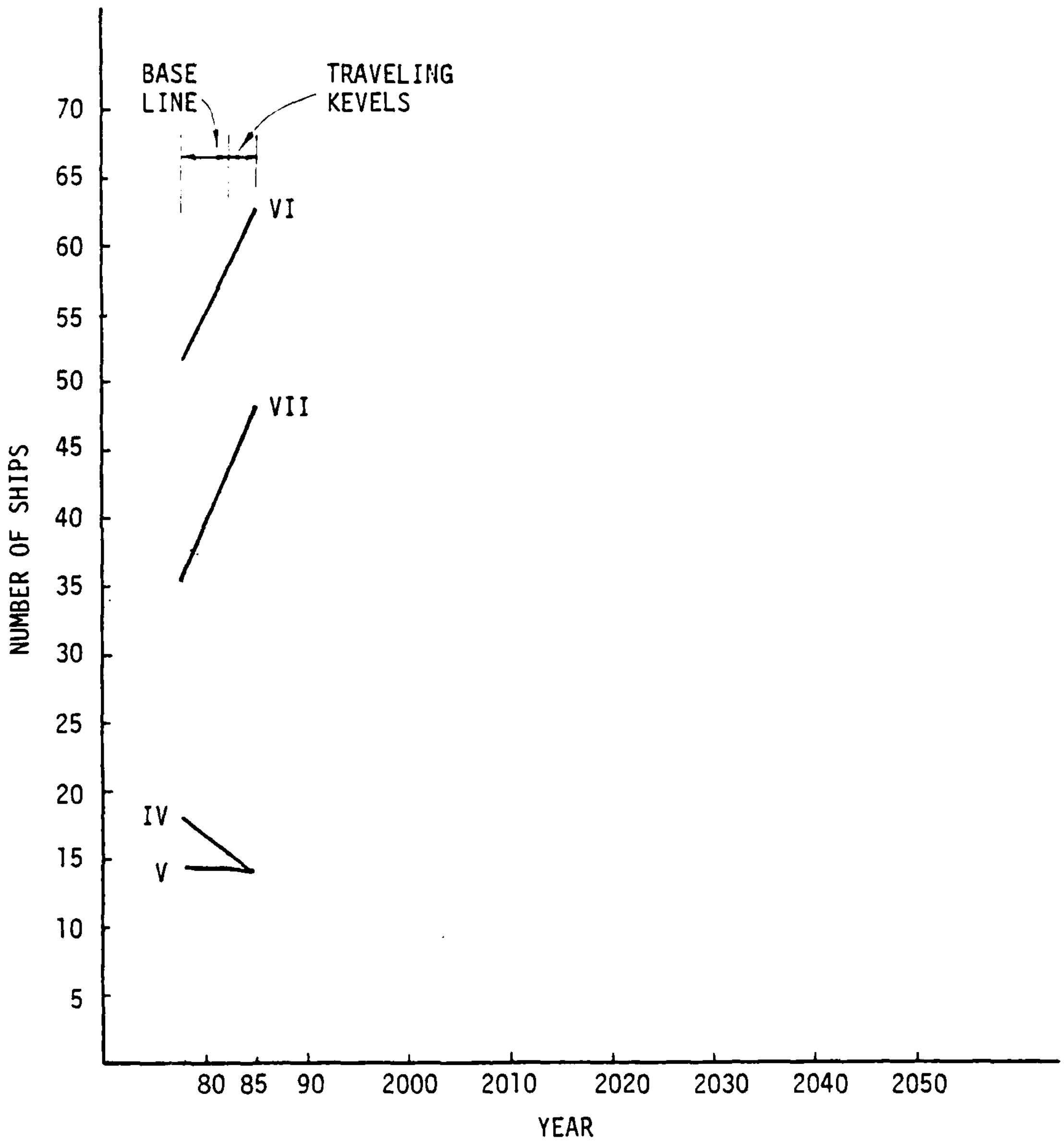

FIGURE 6.4 WELLAND CANAL FLEET MIX - TRAVELING KEVELS

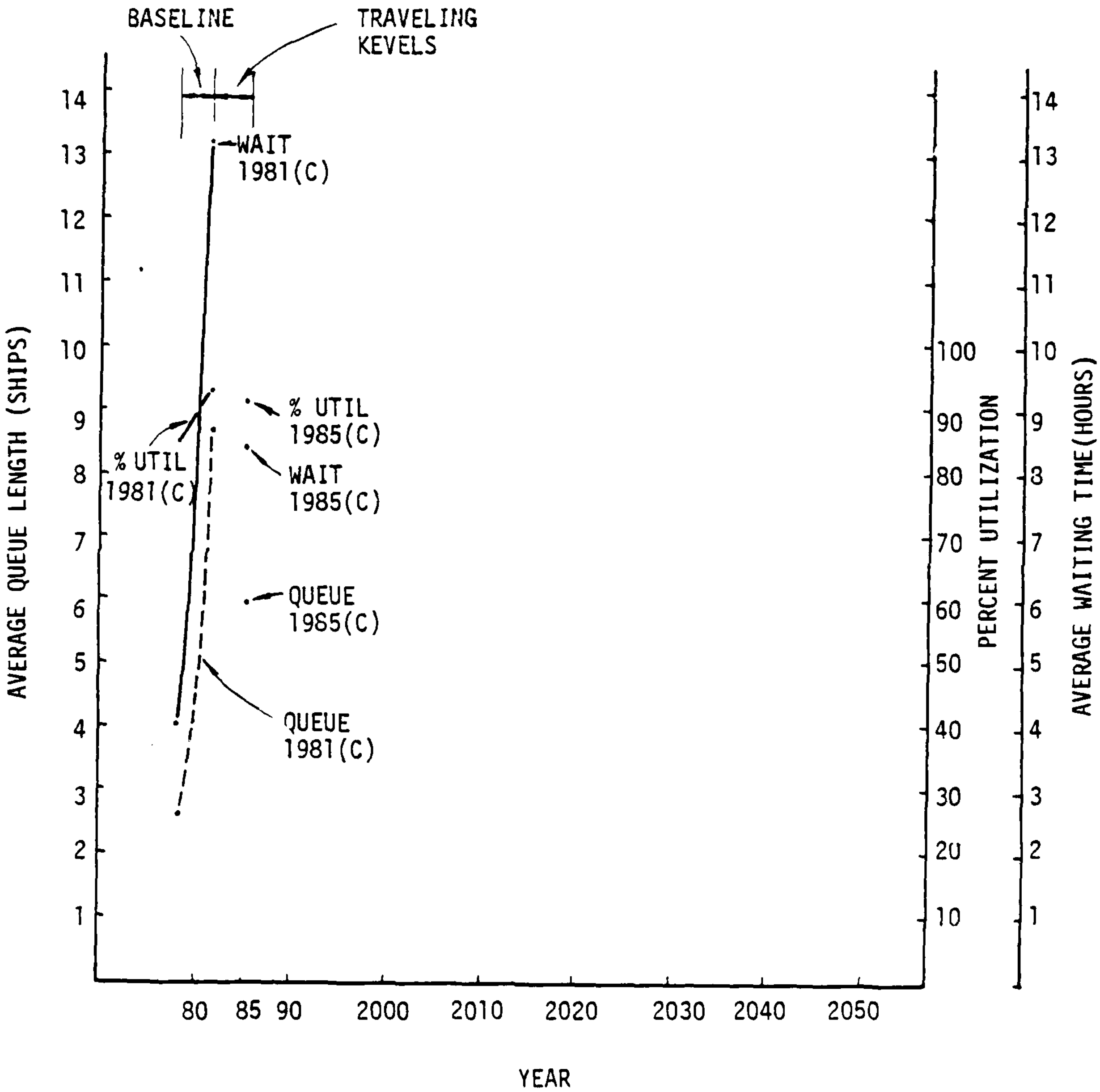

FIGURE 6.5 TRAVELING KEVELS, WELLAND CANAL - QUEUE LENGTH, WAITING TIME, % UTILIZATION; 25.5 FOOT DRAFT

iron ore, and grain. Other bulk increased 13.7%, iron ore increased 10.7%, and grain increased 7.8%.

The total number of ships operating through the St. Lawrence River increased 14.9%, from 143.4 ships in 2006 to 164.8 ships in 2016. The composite ship class for the St. Lawrence River fleet remained constant at 6.1. No increase in capacity through the St. Lawrence River Locks was gained from an increase in fleet vessel size. The St. Lawrence River fleet mix is shown on Figure 6.6.

The total number of transits through the St. Lawrence River Locks increased 8.7%, from 7,910 transits in 2006 to 8,597 transits in 2016. The percentage of loaded transits decreased slightly from 70.0% in 2006 to 69.7% in 2016. This caused a very small decrease in capacity due to an increase in the number of ballasted lockages.

At capacity in 2016 the constraining lock in the St. Lawrence River had an average lock utilization of 90.4% over the peak months of May through November. During July, the most severe month, the lock utilization was 97.0%, the average waiting time was 20.9 hours upbound and 17.3 hours downbound, and the average queue length was 17.3 ships upbound and 14.3 ships downbound. The lock utilization, average vessel waiting time, and average queue length for the constraining lock on the St. Lawrence River are shown in Figure 6.7.

6.3 Increase Ship Speed Entering the Locks

6.3.1 Lock Improvement

To implement this alternative, ships would be instructed to enter the locks at a higher speed. Additional safety procedures and devices would be implemented at the lock to reduce the chance of lock and ship damage. The ship would have to rely to a greater extent than it presently does on the operation of its own controls, particularly the application of reversal of power. This would reduce margins for safety; therefore, additional safety measures would be required to prevent ship and lock damage. Additional safety devices may include replaceable fenders, energy absorbers, and rolling fenders. Some of these devices are currently in place at the Soo Locks and at the St. Lawrence River Locks.

Increasing the ship speed into the lock would increase the lock capacity by reducing the lock entry time component of the locking time. Lock entry time is approximately 15% of the

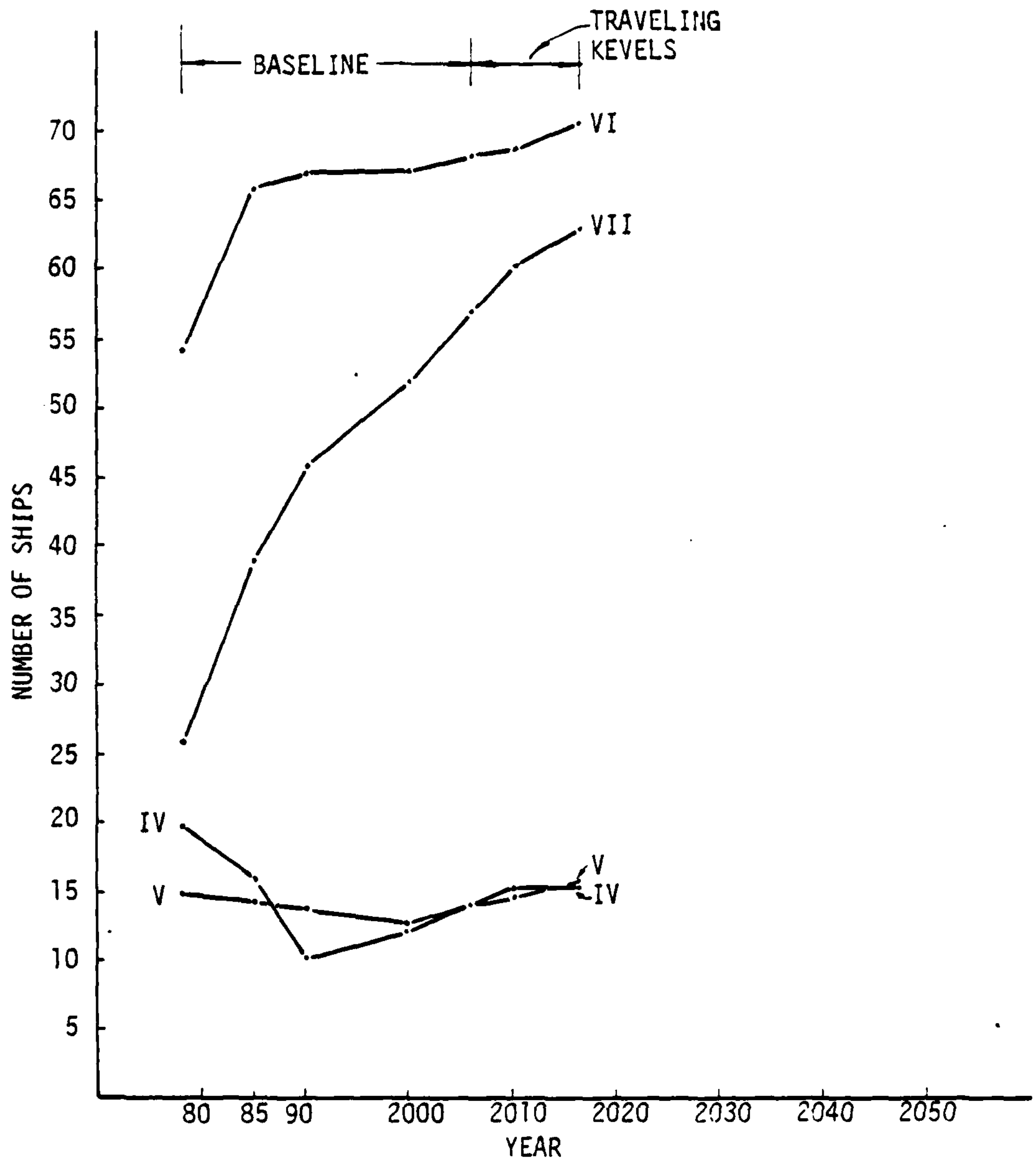

FIGURE 6.6 ST. LAWRENCE RIVER FLEET MIX - TRAVELING KEVELS

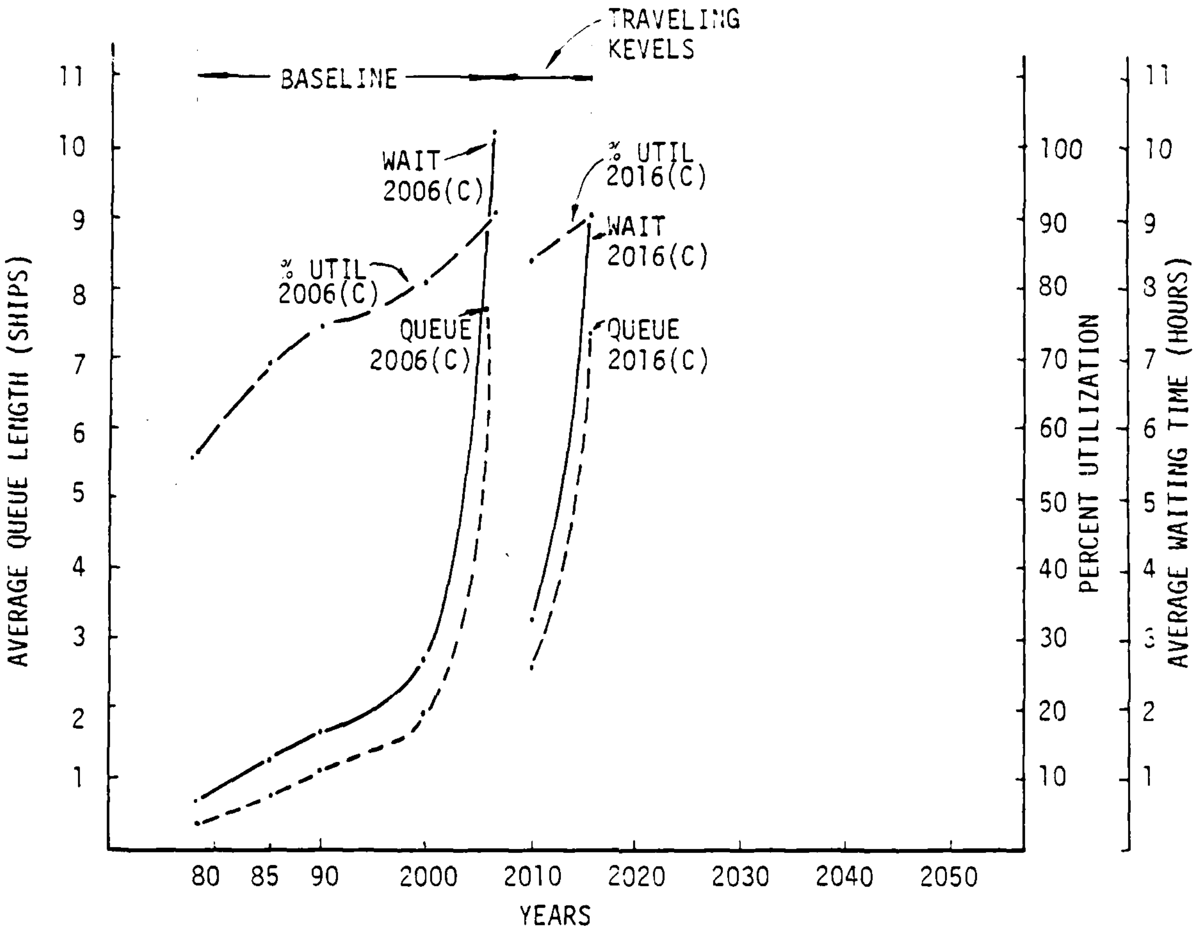

FIGURE 6.7 TRAVELING KEVELS, ST. LAWRENCE RIVER - QUEUE LENGTH, WAITING TIME, % UTILIZATION; 25.5 FOOT DRAFT

total locking time. Increasing the ship speed into the lock would reduce lock entry time approximately 20% at the Soo and St. Lawrence River, and approximately 33% at the Welland Canal. The improvement will reduce locking times to a greater extent at the Welland Canal than at the Soo and St. Lawrence River Locks because ships already enter the soo and St. Lawrence River Locks, which have some safety bumpers and fenders, at higher speeds. Locking time reductions are likely to vary widely between individual ships.

6.3.2 Results of Capacity Simulation Using Increased Ship Speed Entering Locks

6.3.2.1 Soo Locks - With the implementation of increased ship speed entering the locks at the Soo when capacity is reached in 2006, the capacity condition was delayed until 2008. At capacity with ship entrance speed increased in 2008 the amount of cargo processed through the Soo Locks was 177,988,000 short tons. This is an increase of 4,249,000 short tons or 2.4% over the 173,739,000 short tons processed through the lock in 2006.

Most of the increase in cargo between 2006 and 2008 came in iron ore. Iron ore through the Soo Locks increased 2.8%, from 98,911,000 short tons in 2006 to 101,740,000 short tons in 2008.

The number of vessels in the Soo Locks fleet increased 1.8% from 154.3 ships in 2006 to 157.1 ships in 2008. During that two year period, the composite ship class remained constant at 7.0. Figure 6.8 shows the fleet mix for the Soo from 1978 until 2008.

The number of transits through the Soo Locks increased 2.0%, from 10,825 transits in 2006 to 11,041 transits in 2008. The percentage of loaded transits at the Soo Locks remained constant at 55.9%.

Capacity at the Soo was reached at both the Poe and MacArthur Locks in 2008. The Poe Lock had an average lock utilization during the peak months of May through November of 91.3%. During the highest level of traffic in October, the lock utilization was 92.0%, the average vessel waiting time was 3.1 hours upbound and 14.8 hours downbound, and the average queue length was 0.9 ships upbound and 5.1 ships downbound. Lock utilization, average vessel waiting time, and average vessel queue length for the Poe Lock are given on Figure 6.9.

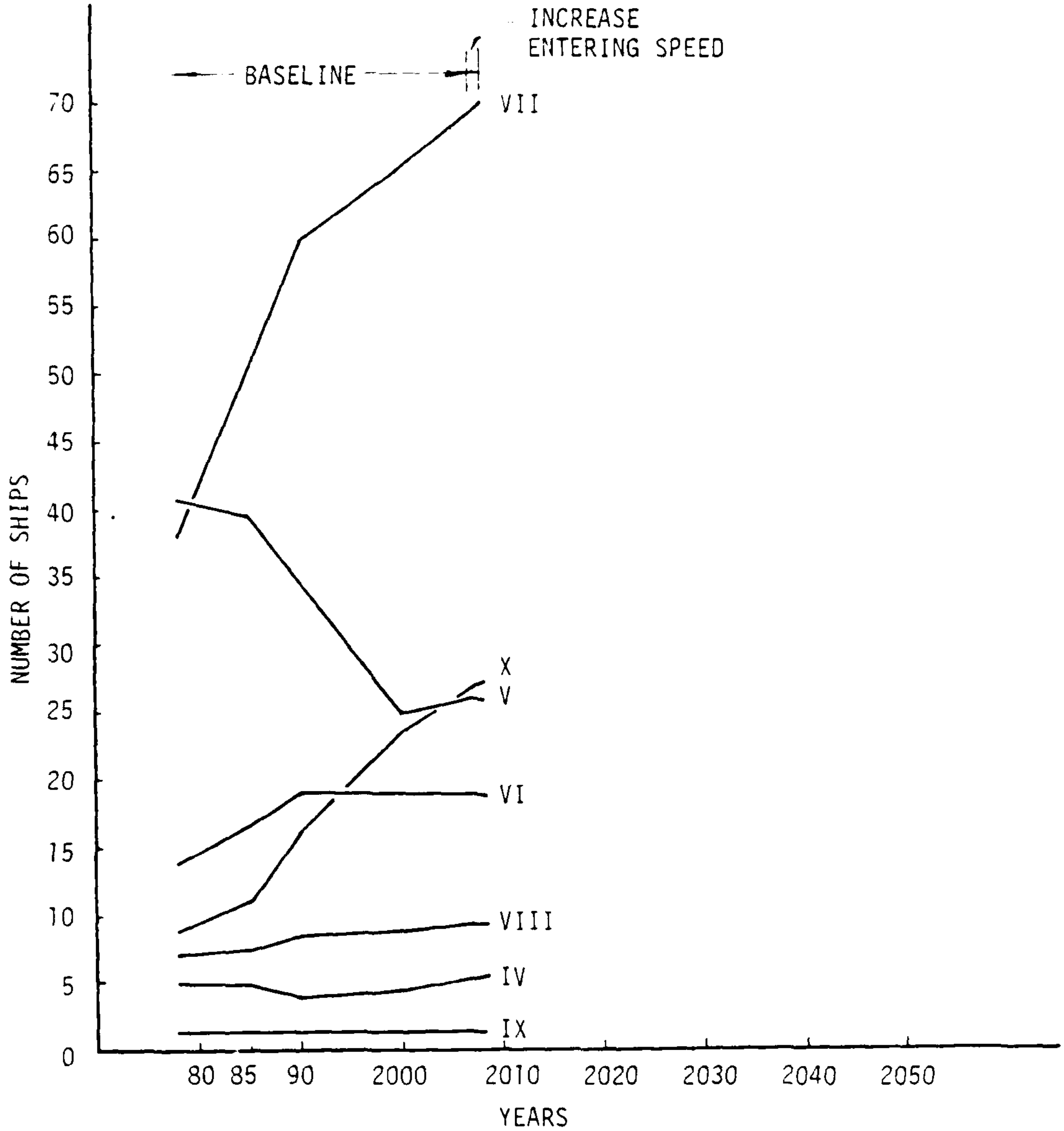

FIGURE 6.8 SOO FLEET MIX - INCREASE SPEED ENTERING LOCKS

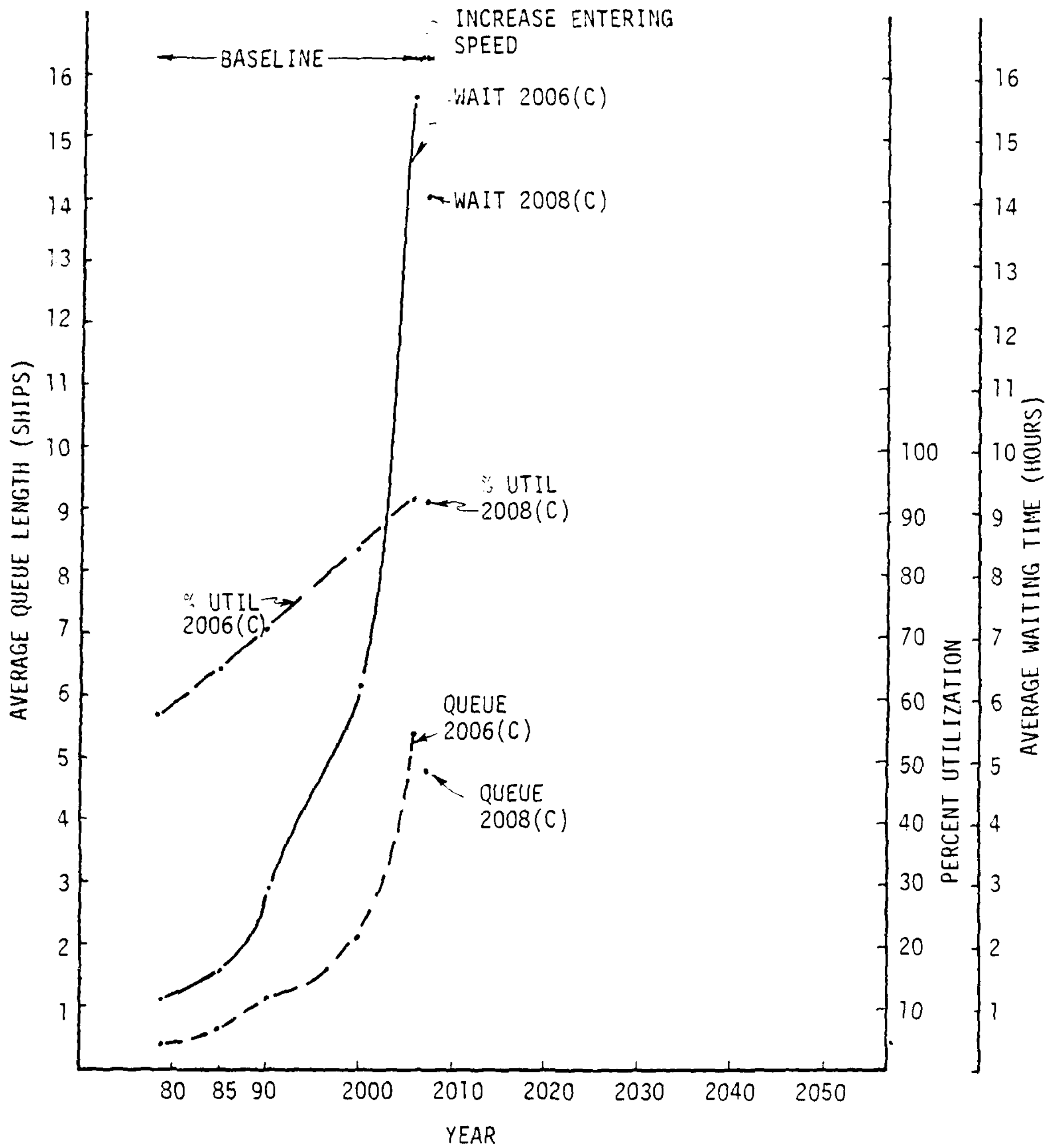

FIGURE 6.9 INCREASE SPEED ENTERING LOCKS, POE LOCK - QUEUE LENGTH, WAITING TIME, % UTILIZATION; 25.5 FOOT DRAFT

The MacArthur Lock had an average lock utilization of 92.4% during the peak months of May through November. During the most severe month, May, lock utilization was 95.0%, average vessel waiting time was 0.3 hours upbound and 13.1 hours downbound, and average queue length was 0.03 ships upbound and 8.3 ships downbound. Lock utilization, average vessel waiting time, and average queue length for the MacArthur Lock are given on Figure 6.10.

6.3.2.2 <u>Welland Canal</u> - After increasing ship speed entering the locks when the original capacity condition occurred in 1981, the Welland Canal again reached capacity in 1984. At capacity in 1984 a total of 78,921,000 short tons of cargo were processed through the Welland Canal. This is an increase of 3,723,000 short tons or 5.0% over the 75,198,000 short tons of cargo processed through the locks in 1981.

The commodities that realized the largest increase in cargo from 1981 to 1984 were general cargo and grain. General cargo increased 17.1%, while grain increased 4.9%.

The number of ships in the Welland Canal fleet increased 4.2% from 130.4 ships in 1981 to 135.9 ships in 1984. The composite ship class for the Welland Canal fleet remained constant at composite class 6.0. The Welland Canal fleet mix is shown on Figure 6.11.

The total number of transits through the Welland Canal increased 3.2%, from 7,268 transits in 1981 to 7,497 transits in 1984. The percentage of loaded transits increased slightly from 64.7% in 1981 to 64.2% in 1984. A small capacity increase was gained from the reduction of ballasted transits.

Lock utilization at the constraining lock on the Welland Canal at capacity in 1984 was an average of 92.3% over the peak months of May through November. During July, the most severe month, the lock utilization was greater than 98%, average vessel waiting time was 29.7 hours upbound and 11.8 hours downbound, and average queue length was 20.9 ships upbound and 11.8 ships downbound. The lock utilization, average vessel waiting time, and average queue length are shown on Figure 6.12.

6.3.2.3 <u>St. Lawrence River</u> - After increasing ship's speed entering the locks upon reaching capacity in 2006, capacity at the St. Lawrence River Locks was delayed until 2010. The amount of cargo passing through the St. Lawrence River Locks at capacity in 2010 was 96,198,000 short tons. This is

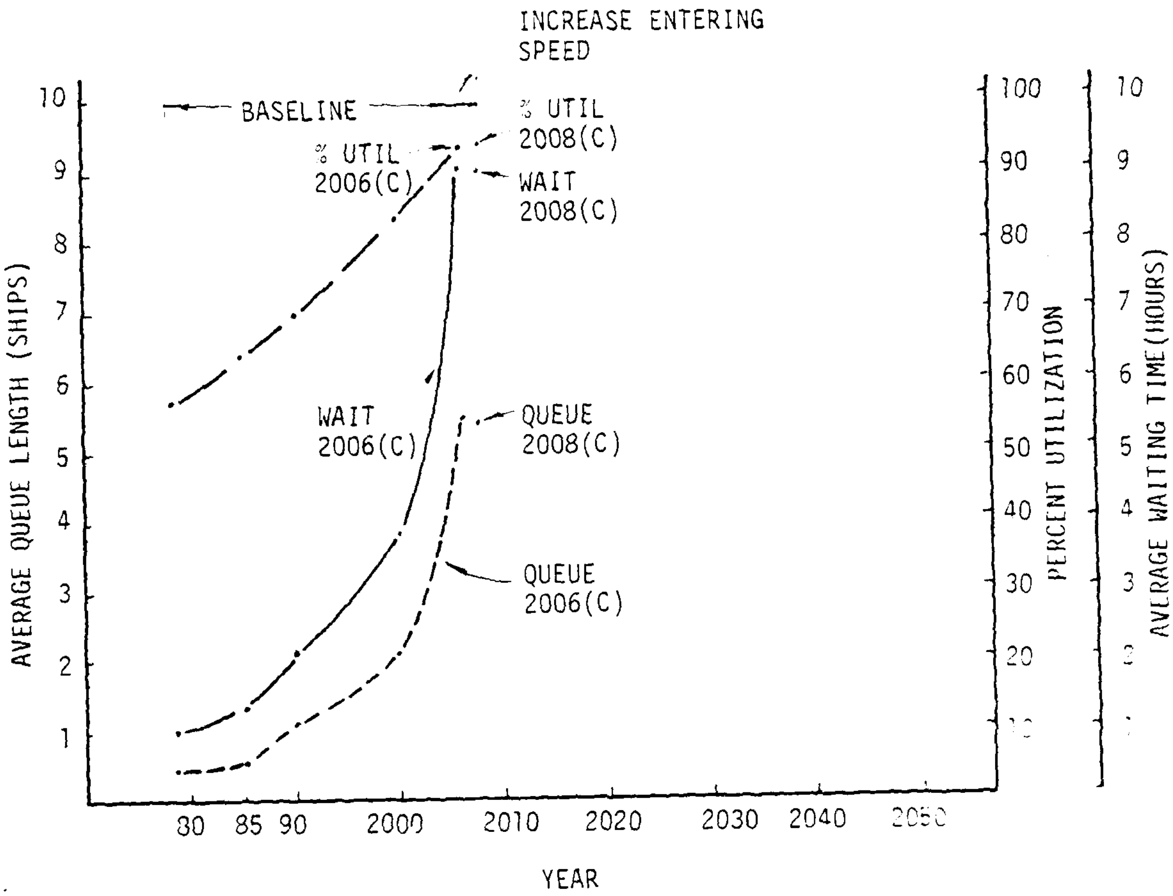

FIGURE 6.10 INCREASE SHIP SPEED ENTERING LOCKS, MacARTHUR LOCK - QUEUE LENGTH, WAITING TIME, % UTILIZATION; 25.5 FOOT DRAFT

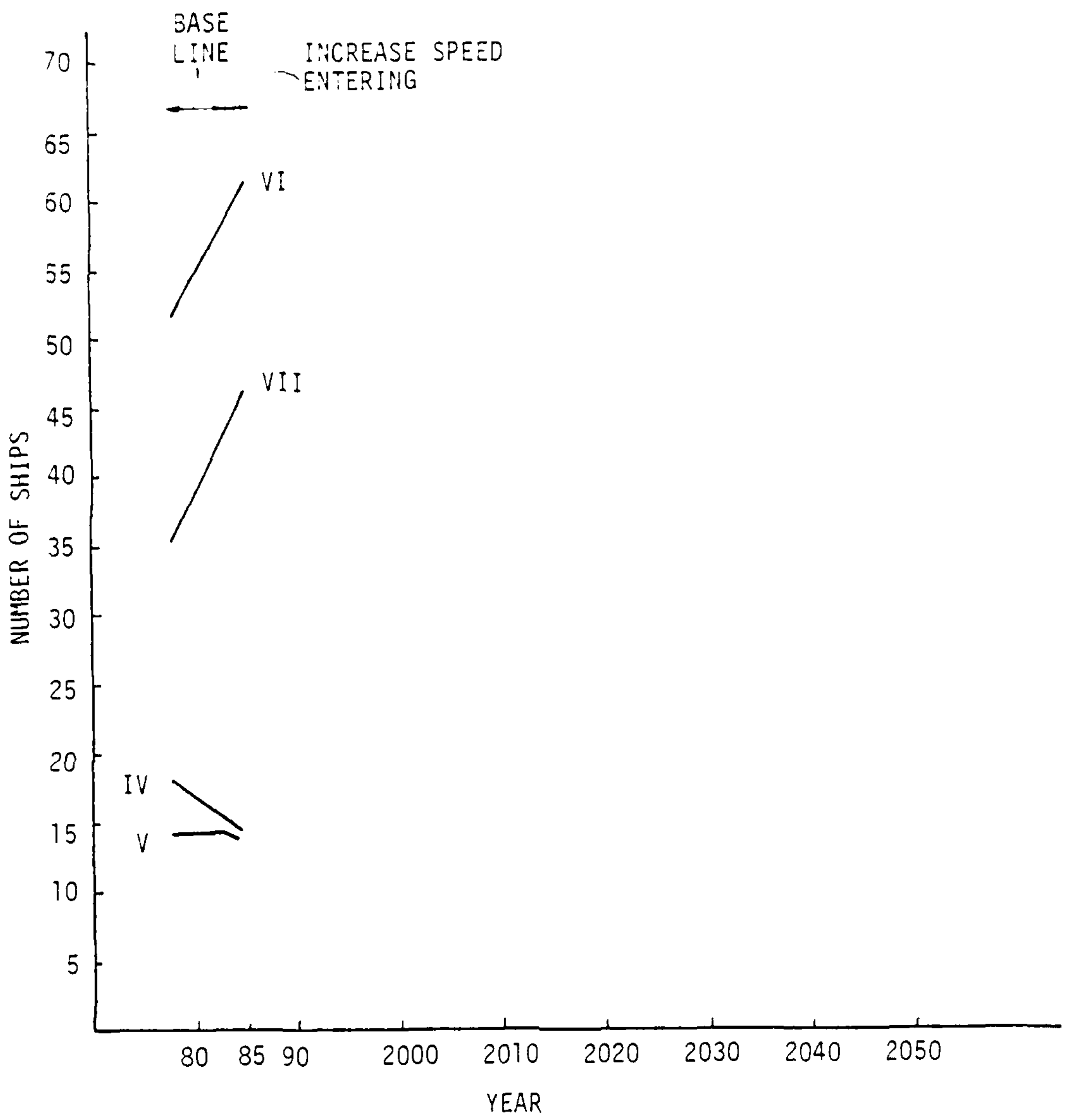

FIGURE 6.11 WELLAND CANAL FLEET MIX - INCREASE SPEED ENTERING LOCKS

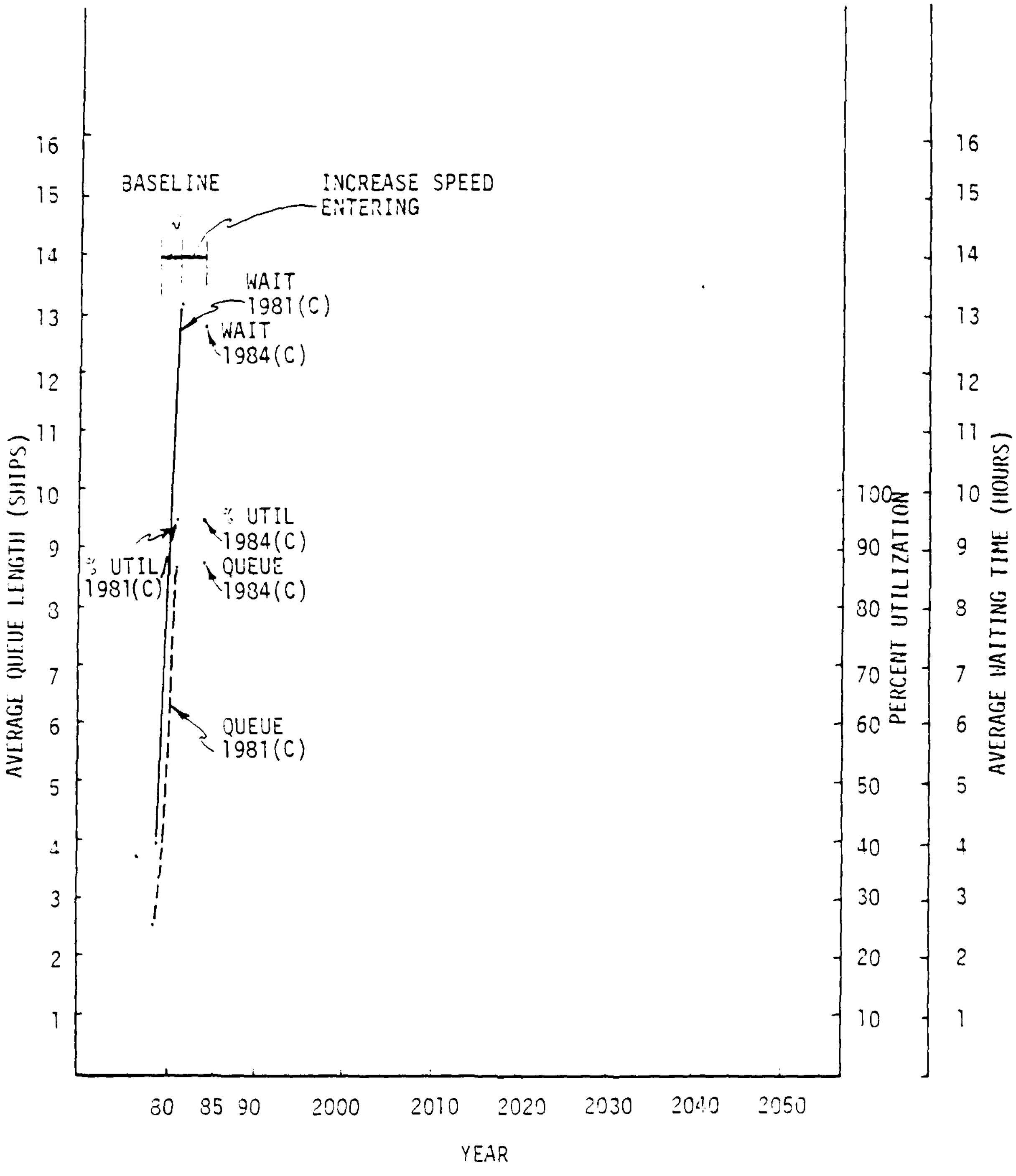

FIGURE 6.12 INCREASE SPEED ENTERING LOCKS, WELLAND CANAL - QUEUE LENGTH, WAITING TIME, % UTILIZATION; 25.5 FOOT DRAFT

an increase of 3,672,000 short tons or 4.0% over the base case capacity in 2006 of 92,526,000 short tons.

Most of the tonnage increase through the St. Lawrence River from 2006 to 2010 was in general cargo, other bulk, iron ore, and grain. General cargo increased 7.0%, other bulk increased 4.4%, iron ore increased 3.9%, and grain increased 2.8%.

The total number of ships operating through the St. Lawrence River increased 10.9%, from 143.4 ships in 2006 to 159.1 ships in 2010. The composite ship class for the St. Lawrence River fleet did not change during that period, remaining at composite class 6.1. The St. Lawrence River fleet mix is shown on Figure 6.13.

The total number of transits through the St. Lawrence River Locks increased 11.0%, from 7,429 transits in 2006 to 8,247 transits in 2010. The percent loaded transits increased only slightly from 70.0% in 2006 to 70.2% in 2010.

At capacity in 2010 the constraining lock in the St. Lawrence River had an average lock utilization of 91.9% over the peak months of May through November. During July, the most severe month, lock utilization was greater than 98.0%, the average vessel waiting time was 30.6 hours upbound and 30.7 hours downbound, and the average queue length was 24.2 ships both upbound and downbound. The lock utilization, average vessel waiting time, and average queue length for the constraining lock on the St. Lawrence River are shown on Figure 6.14.

6.4 Decrease Lock Chambering Time

6.4.1 Lock Improvement

Chambering time, as was defined in Section 5.3.2, consists of several components, two of which include chamber dump/fill times and chamber exit times. Locking time could be reduced by reducing these times. To reduce the dump/fill time, the hydraulic system of the lock would be remodeled or replaced. The flow rate through the culverts and the intake and outlet ports would be increased. The valves would be modified to open and close faster. Exit times could be reduced by providing longitudinal hydraulic assistance for ships exiting downstream. Water would be allowed to enter the chamber through the filling ports from

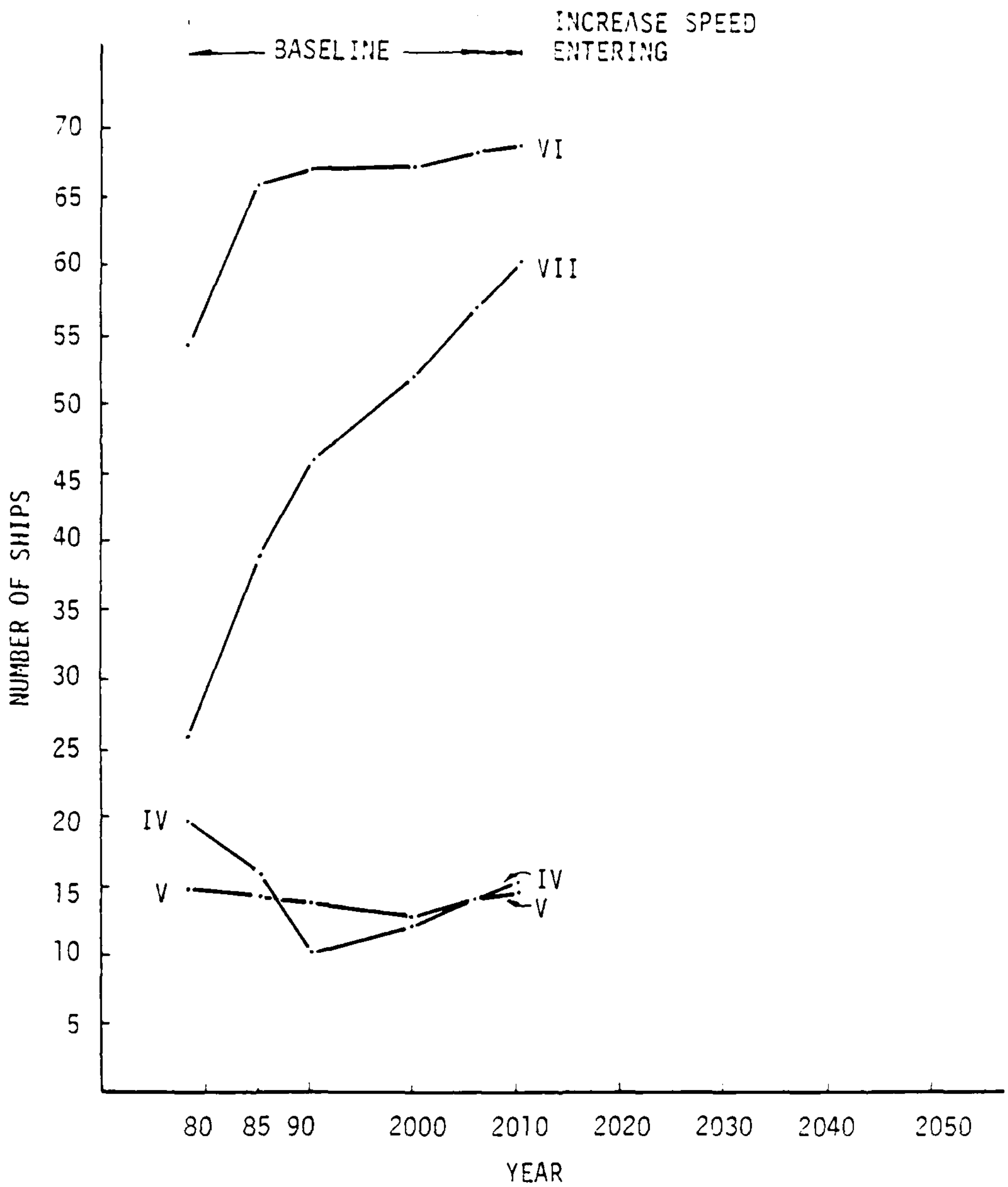

FIGURE 6.13 ST. LAWRENCE RIVER FLEET MIX - INCREASE SPEED IN LOCKS

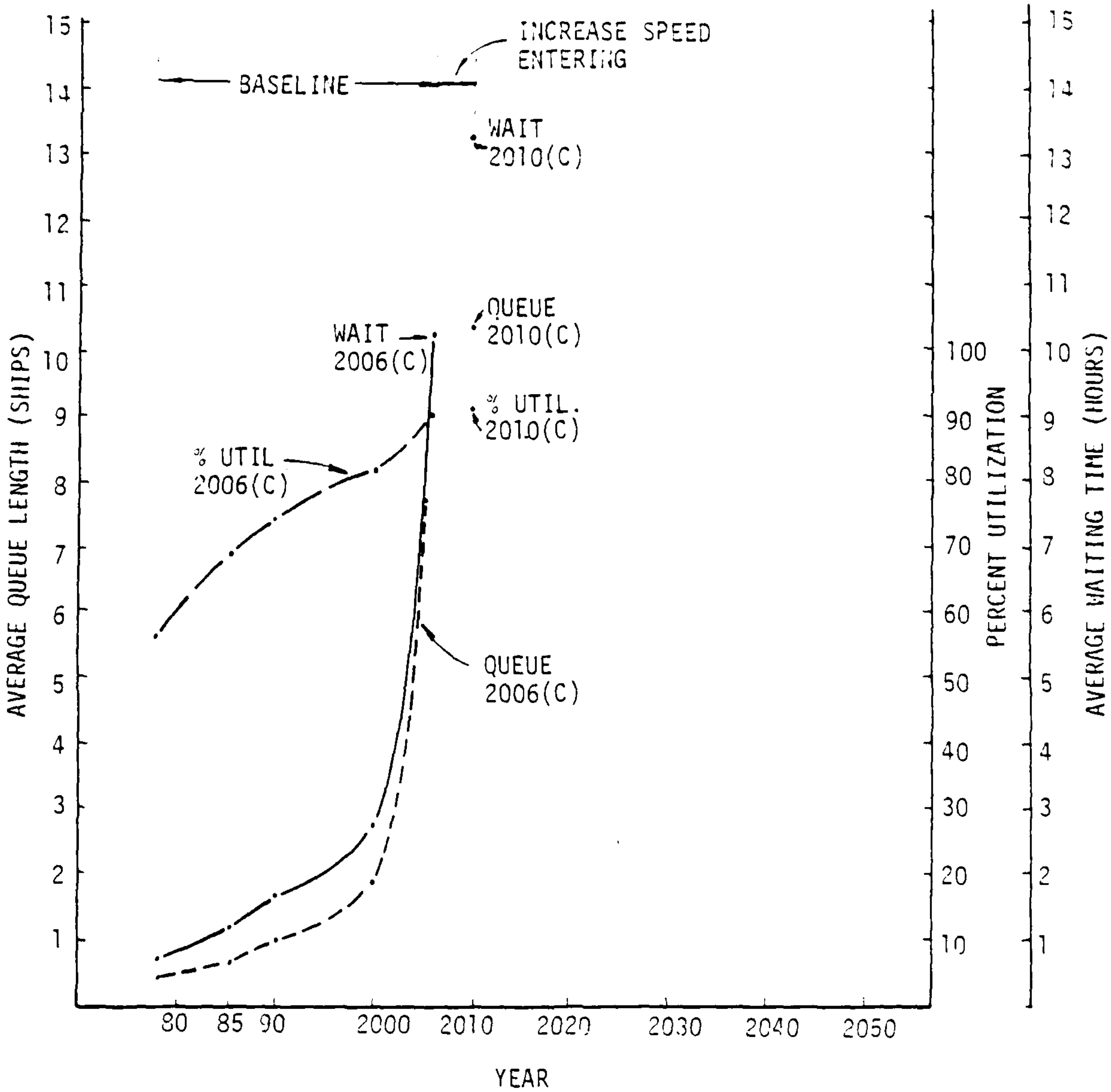

FIGURE 6.14 INCREASE SPEED ENTERING LOCKS, ST. LAWRENCE RIVER QUEUE LENGTH, WAITING TIME, % UTILIZATION; 25.5 FOOT DRAFT

the upstream side to hydraulically assist the exit of downbound vessels. Implementation of this alternative would decrease the lock chambering times and thereby reduce the lock cycle time.

Chambering time is approximately 15% of the total locking time at the Welland Canal Locks, and approximately 10% of the total locking time at the Soo and St. Lawrence River Locks. By expanding the hydraulics of the locks, chambering could conceivably be reduced 10% at the Soo and St. Lawrence River and 15% at the Welland Canal. The corresponding reduction in total locking time would be 1% at the Soo and St. Lawrence River Locks and 2.5% at the Welland Locks. Downstream longitudinal hydraulic assistance could be expected to reduce the downstream locking time an additional 4.5% at the Soo and St. Lawrence River Locks and 2.5% at the Welland Canal. Chambering times can be improved more at the Welland Canal Locks which have smaller capacity dump/fill culverts than at the Soo and St. Lawrence River Locks. Downstream longitudinal hydraulic assitance will reduce exit times more at the Soo and St. Lawrence River Locks, where it is not in use at the constraining lock, than at the Welland Locks where it is used to some extent.

6.4.2 Results of Capacity Simulation Using Decreased Lock Chambering Times

6.4.2.1 Soo Locks - With implementation of a revised hydraulic system and downstream longitudinal hydraulic assistance at the Soo Locks when capacity was reached in 2006, the capacity condition was delayed until 2010. At capacity with the reduced chambering times in 2010, the amount of cargo processed through the Soo Locks was 182,250,000 short tons. This is an increase of 8,511,000 short tons or 4.9% over the 173,739,000 short tons processed through the locks in 2006.

Most of the increase in cargo between 2006 and 2010 was in iron ore and grain. Iron ore increased 5.6%, while grain increased 3.1%.

The number of vessels in the Soo Locks fleet increased 3.8%, from 154.3 ships in 2006 to 160.1 ships in 2010. The composite ship class for the Soo fleet increased slightly from 7.0 to 7.1 due to slight increaces in the sizes of the ore, coal, and stone fleets. A slight gain in capacity was realized from this increase. The Soo fleet mix from 1978 to 2010 is shown on Figure 6.15.

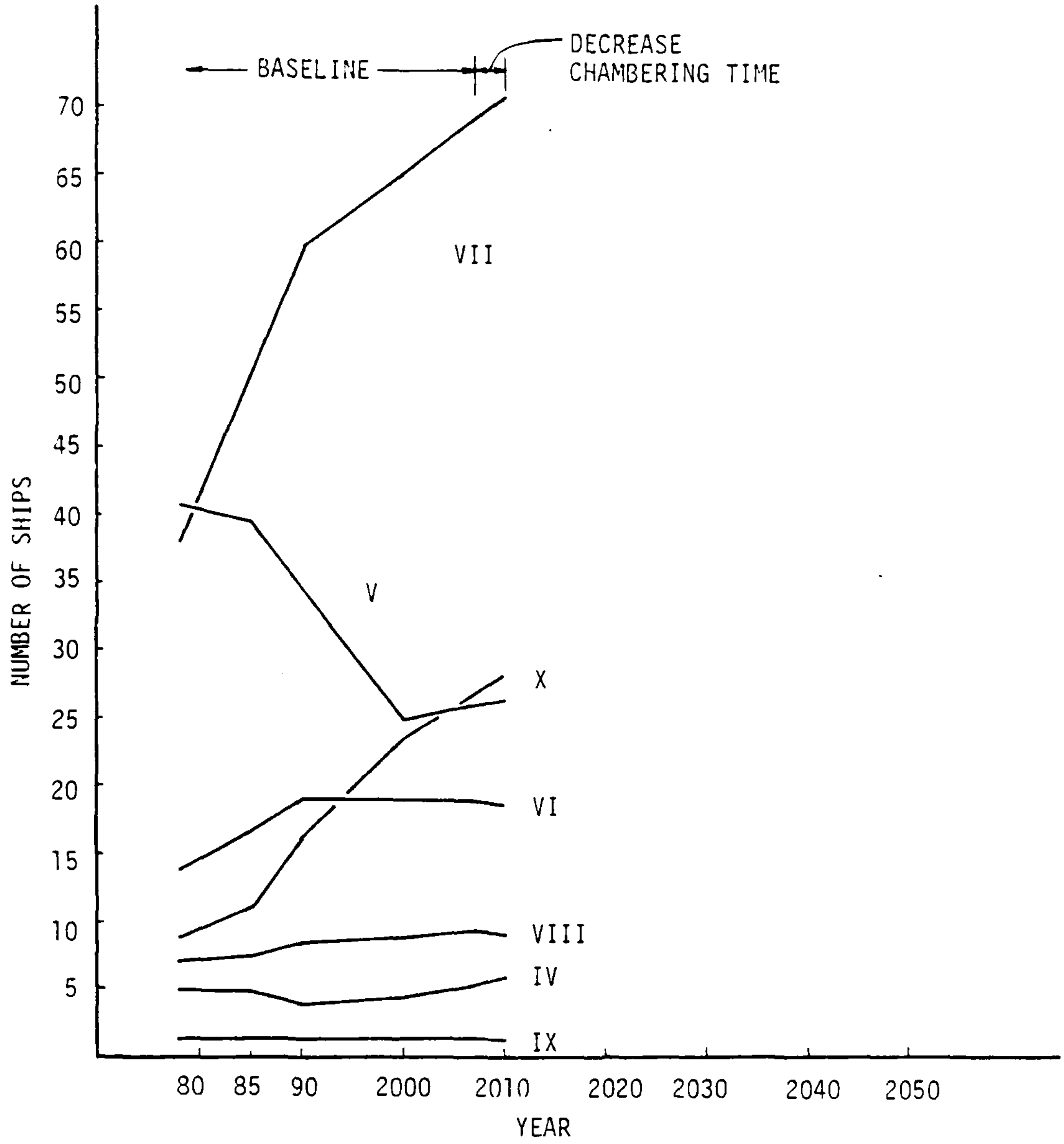

FIGURE 6.15 SOO FLEET MIX - DECREASE LOCK CHAMBERING TIME

The total number of transits through the Soo Locks increased 3.9%, from 10,825 transits in 2006 to 11,246 transits in 2010. The percent loaded transits remained constant at 55.7% from 2006 to 2010.

Capacity at the Soo was reached by both the Poe and MacArthur Locks in 2010. The Poe Lock had an average lock utilization during the peak months of May through November of 91.6%. During the most severe traffic month, October, lock utilization was 92.0%, the average vessel waiting time was 3.7 hours upbound and 14.7 hours downbound, and the average queue length was 0.9 ships upbound and 5.1 ships downbound. Lock utilization, average vessel waiting time, and average queue length for the Poe Lock are given on Figure 6.16.

The MacArthur Lock had an average lock utilization of 92.1% during the peak months of May through November. During the period of peak traffic in May, the MacArthur Lock had a lock utilization of 93.0%, average vessel waiting time of 0.3 hours upbound and 7.9 hours downbound, and average queue length of 0.03 ships upbound and 6.3 ships downbound. Lock utilization, average vessel waiting time, and vessel queue length for the MacArthur Lock are given on Figure 6.17.

6.4.2.2 Welland Canal - After improving the hydraulic system and adding downstream longitudinal hydraulic assistance at the original capacity condition in 1981, the Welland Canal again reached capacity in 1983. At capacity in 1983 a total of 78,839,000 short tons of cargo were processed through the Welland Canal. This is an increase of 3,641,000 short tons, or 4.8%, over the 75,198,000 short tons of cargo that passed through the locks in 1981.

The commodities that realized the largest increases in cargo from 1981 to 1983 were general cargo and grain. General cargo increased 16.7% and grain increased 3.5%.

The number of ships in the Welland Canal fleet increased 4.2%, from 130.4 ships in 1981 to 135.9 ships in 1983. The composite ship class for the Welland Canal fleet mix is shown on Figure 6.18.

The total number of transits through the Welland Canal increased 3.1%, from 7,268 transits in 1981 to 7,496 transits in 1983. The percent loaded transits increased from 64.7% in 1981 to 54.2% in 1983 causing a slight increase in capacity due to a reduction in ballasted transits.

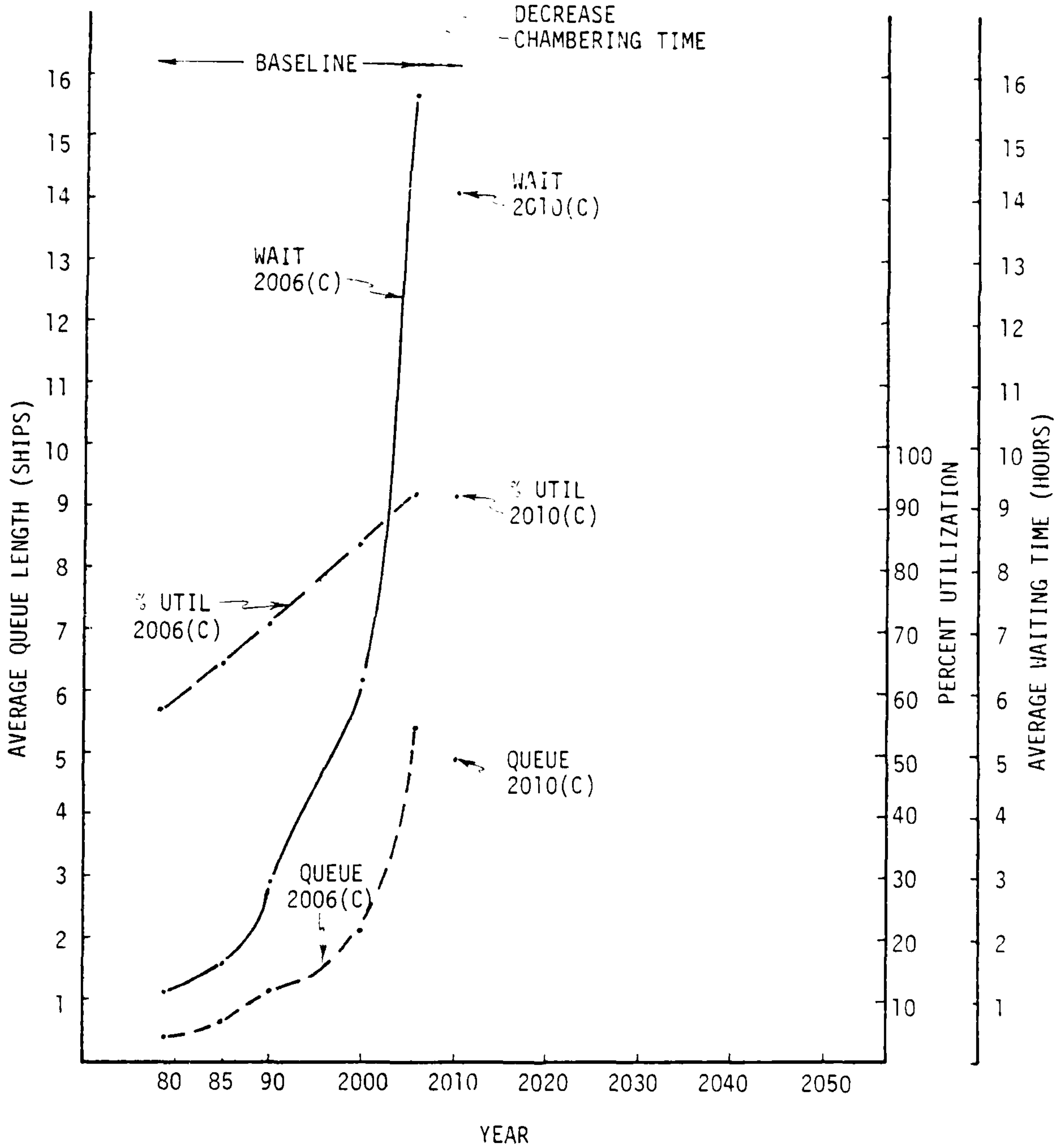

FIGURE 6.16 DECREASE LOCK CHAMBERING TIME, POE LOCK - QUEUE LENGTH, WAITING TIME, % UTILIZATION; 25.5 FOOT DRAFT

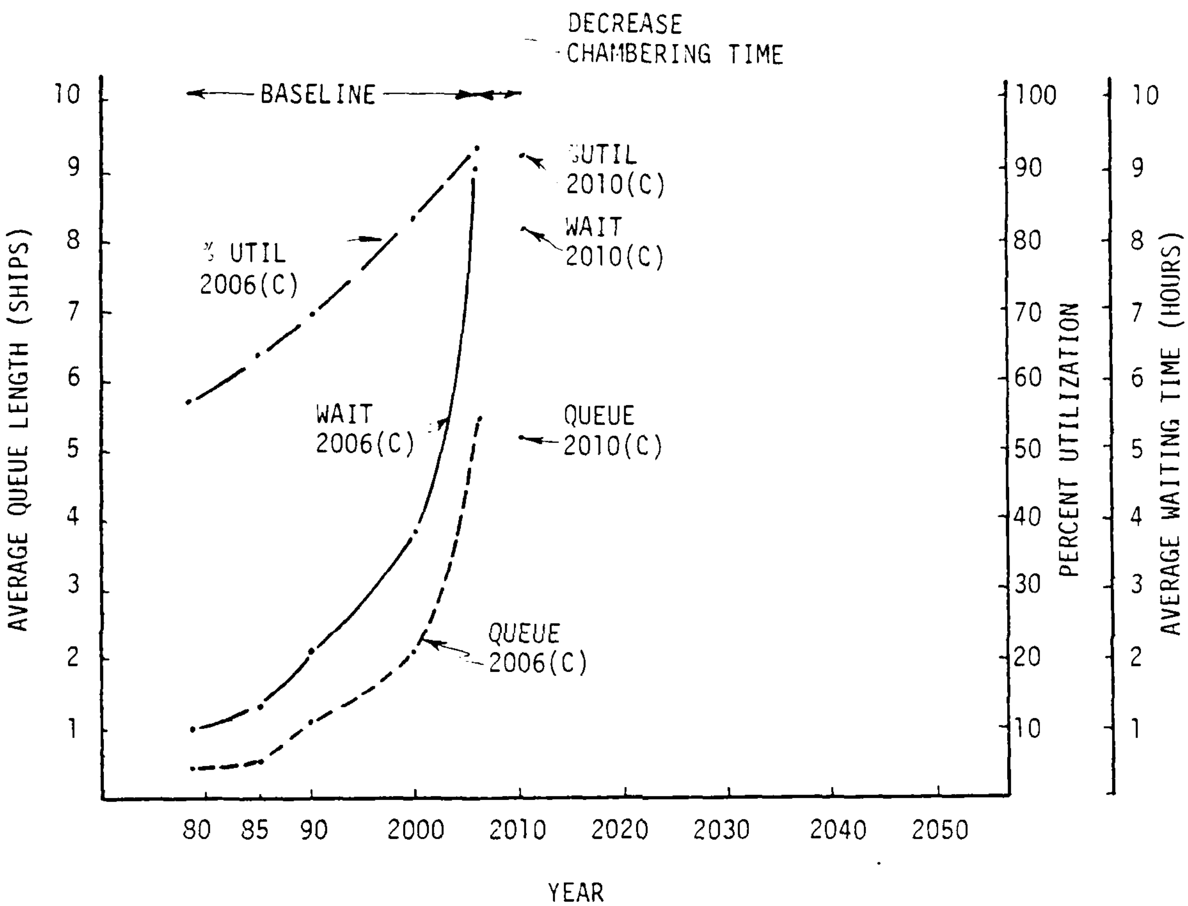

FIGURE 6.17 DECREASE LOCK CHAMBERING TIME, MacARTHUR LOCK, QUEUE LENGTH, WAITING TIME, % UTILIZATION; 25.5 FOOT DRAFT

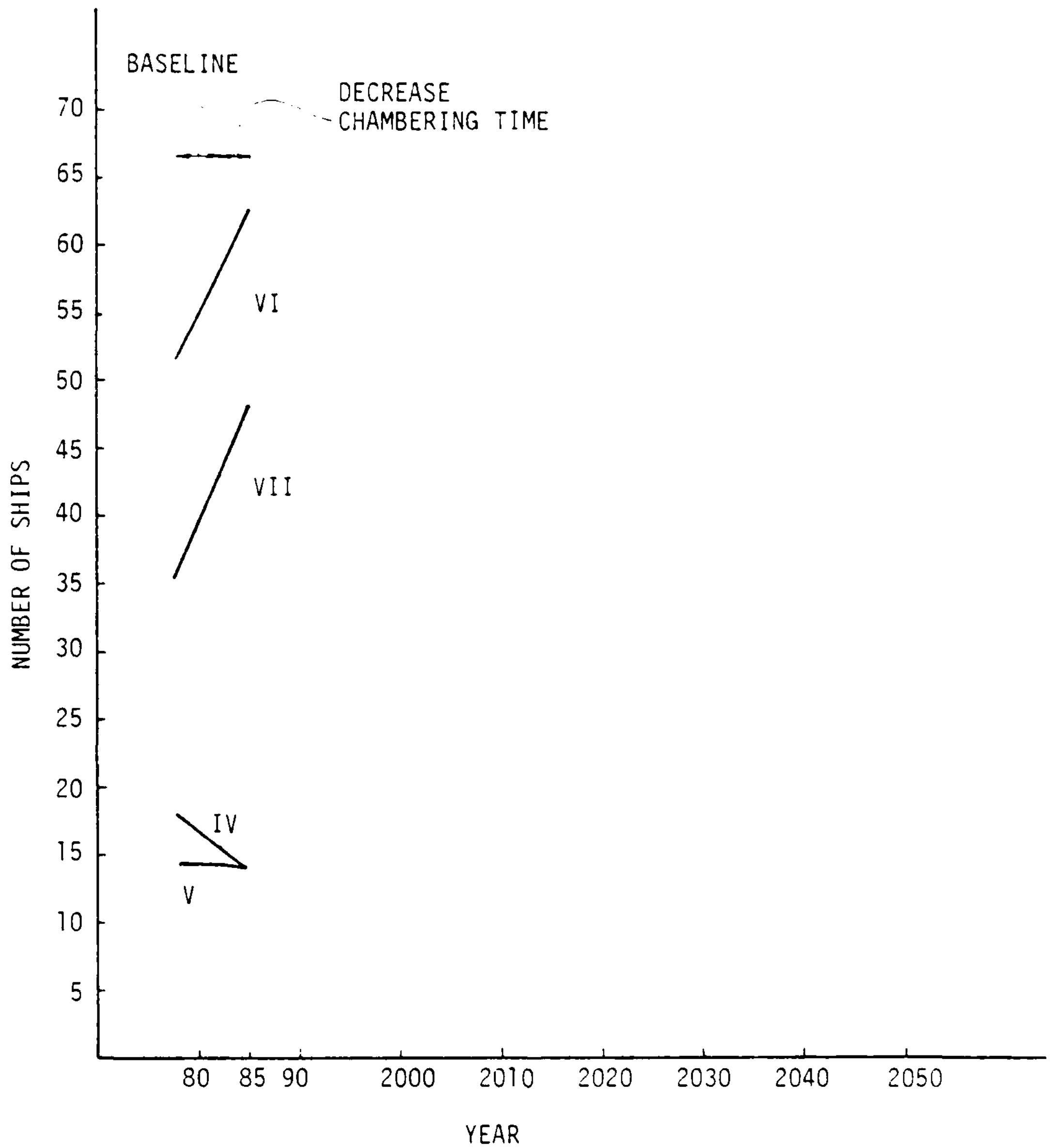

FIGURE 6.18 WELLAND CANAL FLEET MIX - DECREASE LOCK CHAMBERING TIME

Lock utilization at the constraining lock on the Welland Canal at capacity in 1983 was an average of 94.4% over the peak months of May through November. During July, the most severe month, the lock utilization was greater than 98%, and average vessel waiting time was 34.9 hours upbound and 18.1 hours downbound. The average queue length was 24.2 ships upbound and 12.7 ships downbound. The lock utilization, average vessel waiting time, and average queue length are shown on Figure 6.19.

6.4.2.3 St. Lawrence River - With implementation of revised hydraulic systems and downstream longitudinal hydraulic assistance upon reaching capacity in 2006, capacity on the St. Lawrence River Locks was delayed until 2010. The amount of cargo processed through the St. Lawrence River Locks at capacity in 2010 was 96,353,000 short tons. This is an increase of 3,827,000 short tons or 4.1% over the base case capacity in 2006 of 92,526,000 short tons.

Most of the tonnage increase through the St. Lawrence River from 2006 to 2010 was spread among general cargo, other bulk, iron ore, and grain. General cargo increased 7.1%, other bulk increased 4.6%, iron ore increased 3.9%, and grain increased 3.1%.

The total number of ships operating through the St. Lawrence River increased 10.9%, from 143.4 ships in 2006 to 159.1 ships in 2010. The composite ship class for the St. Lawrence River fleet remained constant at composite class 6.1. Capacity of the St. Lawrence River Locks was not increased by an increase in ship size. The St. Lawrence River fleet mix is shown on Figure 6.20.

The total number of transits through the St. Lawrence River Locks increased 11.0%, from 7,429 transits in 2006 to 8,246 transits in 2010. The percent loaded transits increased slightly from 70.0% in 2006 to 70.2% in 2010, giving a slight capacity increase due to a reduced fraction of ballasted transits.

At capacity in 2010 the constraining lock in the St. Lawrence River had an average lock utilization of 91.9% over the peak months of May through November. During July, the most severe month, lock utilization was greater than 98.0%, the average vessel waiting time was 30.6 hours upbound and 15.7 hours downbound, and the average queue length was 24.1 ships upbound and 12.4 ships downbound. The lock utilization, average vessel waiting time, and average queue length for the constraining lock on the St. Lawrence River are shown on Figure 6.21.

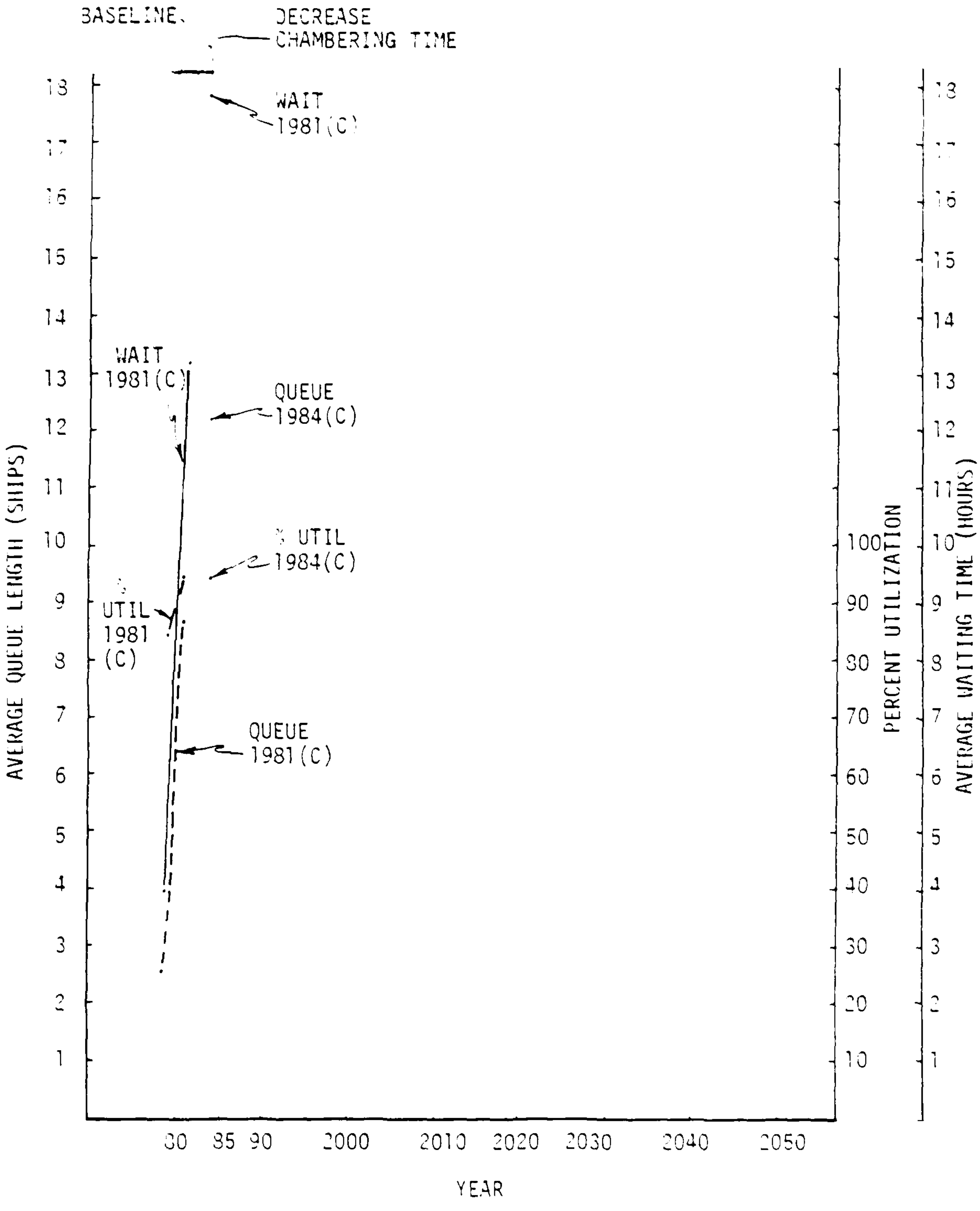

FIGURE 6.19 DECREASE CHAMBERING TIME, WELLAND CANAL - QUEUE LENGTH, WAITING TIME, % UTILIZATION; 25.5 FOOT DRAFT

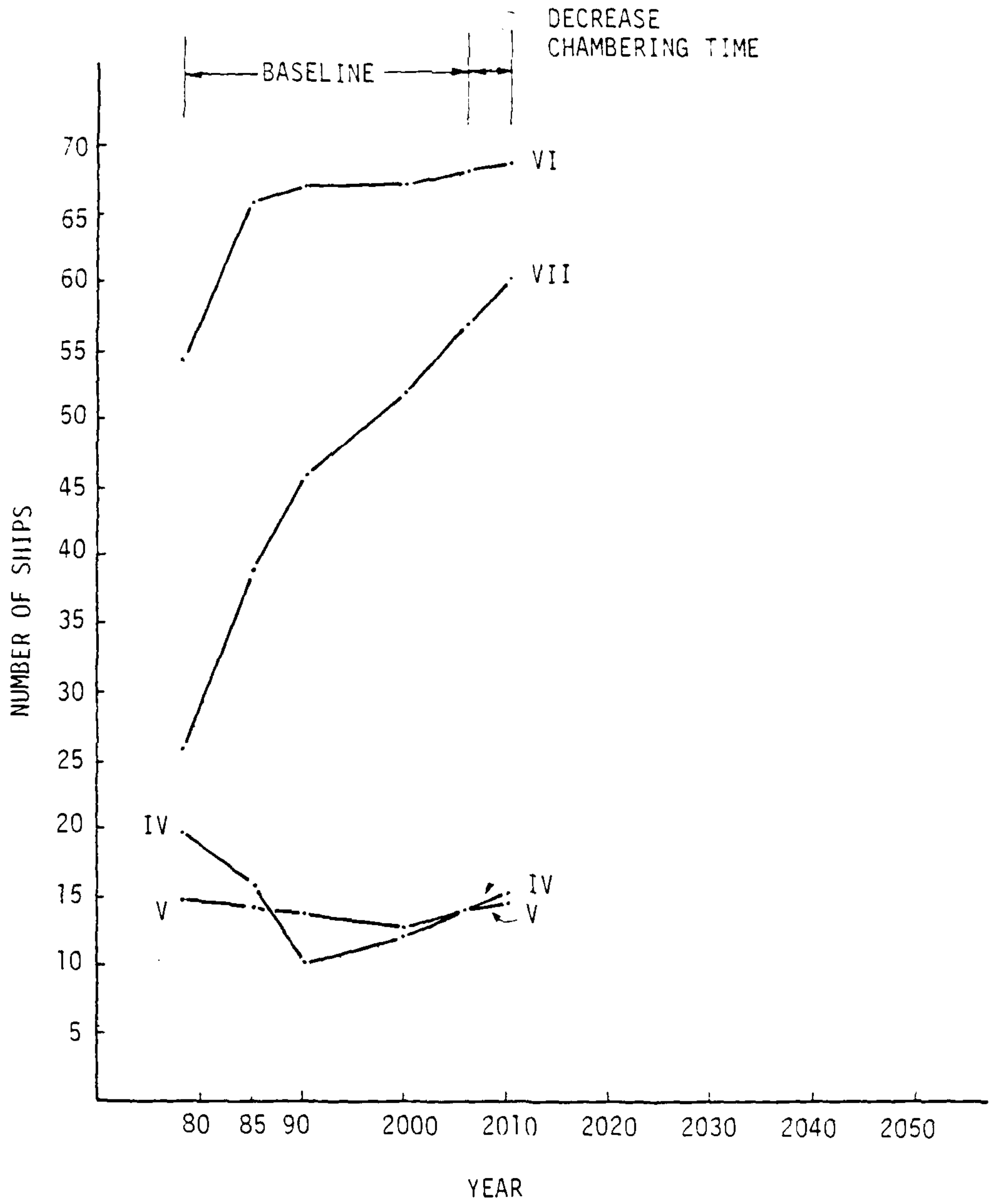

FIGURE 6.20 ST. LAWRENCE RIVER FLEET MIX - DECREASE LOCK CHAMBERING TIME

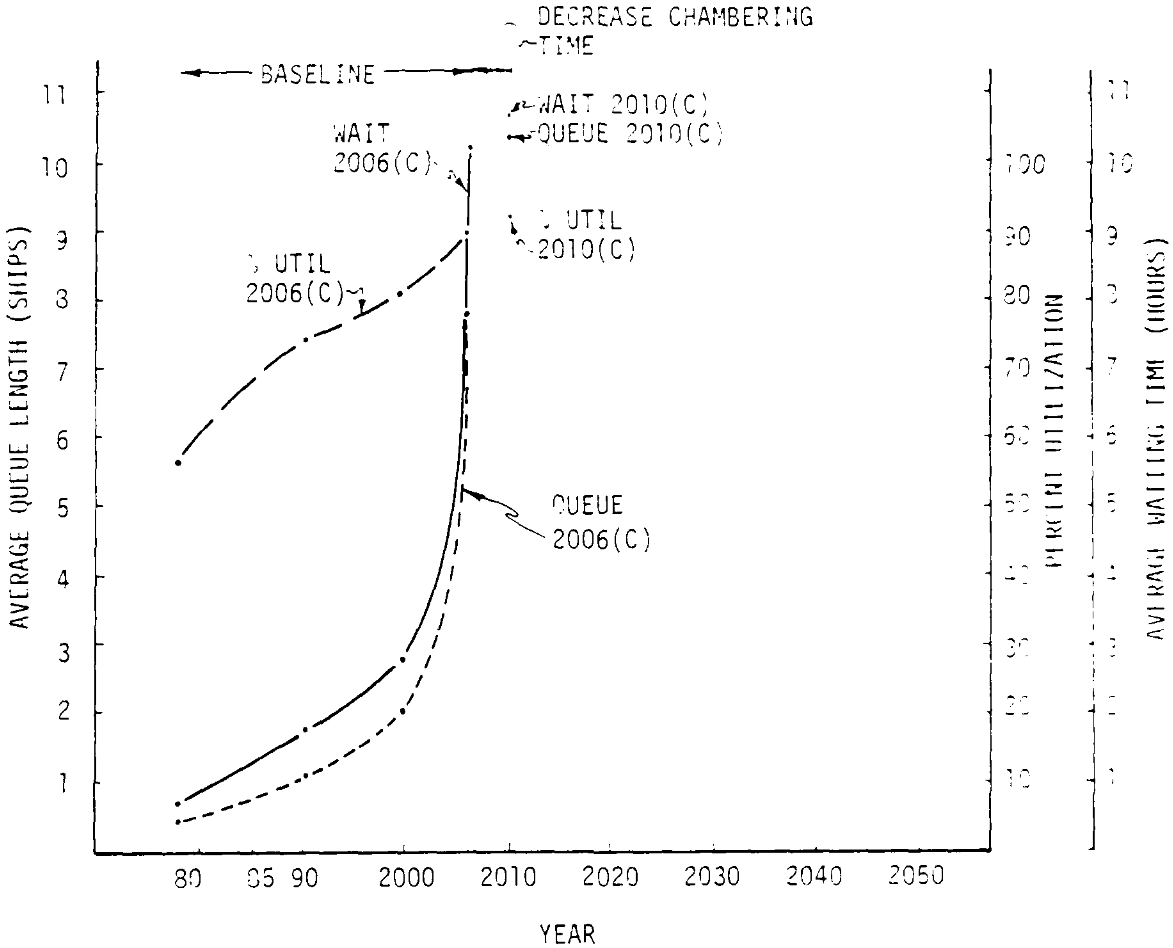

FIGURE 6.21 DECREASE CHAMBERING TIME, ST. LAWRENCE RIVER, QUEUE LENGTH, WAITING TIME, % UTILIZATION; 25.5 FOOT DRAFT

6.5 Traffic Control System at Locks

6.5.1 Lock Improvement

The proposed traffic control system would consist of a central, computer run control point for each of the three lock systems. Information concerning all of the ships approaching or in the lock system would be input. The system would plan ship arrivals at the lock to reduce lock approach times. Ship meetings at restricted channel sections would also be planned to increase safety. Instructions would be relayed to the ship captains by radio from lock traffic controllers at the central control station. The proposed traffic control system would be designed to reduce delays in lock approaches and would allow faster responses by the lock operators in the locking operation.

Approach time is approximately 20% of the total locking time at the Soo and St. Lawrence River Locks, and 25% of the total at the Welland Canal Locks. The proposed traffic control system would have the potential to reduce approach times approximately 22% at the Soo and St. Lawrence River, and approximately 12% at the Welland Canal. It is estimated that total locking times would correspondingly be reduced 4.5% at the Soo and St. Lawrence River Locks, and 3.0% at the Welland Locks. The proposed control system would reduce locking times more at the Soo and St. Lawrence River because the present means of traffic control at these locks are less sophisticated than that in use at the Welland Canal. It is judged, however, that the system in use at the Welland also has potential for some improvement.

6.5.2 Results of Capacity Simulation Using Traffic Control System at the Locks

6.5.2.1 Soo Locks - With implementation of a traffic control system at the Soo Locks when capacity was reached in 2006, the capacity condition was delayed until 2010. At capacity with the traffic control system implemented, the amount of cargo processed through the Soo Locks was 182,250,000 short tons. This is an increase of 8,511,000 short tons or 4.9% over the 173,739,000 short tons processed through the lock in 2006.

Most of the increase in cargo between 2006 and 2010 came in iron ore and grain. Iron ore increased 5.6% and grain increased 3.1%.

The number of vessels in the Soo Locks fleet increased 3.7%, from 154.3 ships in 2006 to 160.0 ships in 2010. The

composite ship class for the Soo fleet increased slightly from 7.0 in 2006 to 7.1 in 2010. A slight increase in capacity was realized due to the small increase in ship size. The Soo fleet mix from 1978 to 2010 is shown in Figure 6.22.

The total number of transits through the Soo Locks increased 3.9%, from 10,825 transits in 2006 to 11,246 transits in 2010. The percent loaded transits remained constant at 55.8%; therefore, there was no capacity increase due to a reduced fraction of empty backhauls.

Capacity at the Soo was reached by both the Poe and MacArthur Locks in 2010. The Poe Lock had an average lock utilization during the peak months of May through November of 91.6%. During the most severe month, October, the lock utilization was 92.0%, the average vessel waiting time was 3.2 hours upbound and 15.0 hours downbound, and the average queue length was 0.8 ships upbound and 5.2 ships downbound. Lock utilization, average vessel waiting time, and average queue length for the Poe Lock are given on Figure 6.23.

The MacArthur Lock had an average lock utilization of 92.3% during the peak months of May through November. During the most severe month, May, lock utilization was 94.0%, average vessel waiting time was 0.3 hours upbound and 10.8 hours downbound, and average queue length was 0.03 ships upbound and 6.9 ships downbound. Lock utilization, average vessel waiting time, and average queue length for the MacArthur Lock are given on Figure 6.24.

6.5.2.2 Welland Canal - After implementation of a traffic control system at the original capacity condition in 1981, the Welland Canal again reached capacity in 1983. At capacity in 1983 a total of 78,735,000 short tons of cargo were processed through the Welland Canal. This is an increase of 3,536,000 short tons or 4.7% over the 75,198,000 short tons of cargo processed through the locks in 1981.

The commodities that had the largest increases in cargo from 1981 to 1983 were general cargo and grain. General cargo increased 16.5% and grain increased 4.9%.

The number of ships in the Welland Canal fleet increased 4.2%, from 130.4 ships in 1981 to 135.9 ships in 1983. The composite ship class for the Welland Canal fleet remained at 6.0. Lock capacity was therefore not increased as the result of increasing ship size. The Welland Canal fleet mix is shown on Figure 6.25.

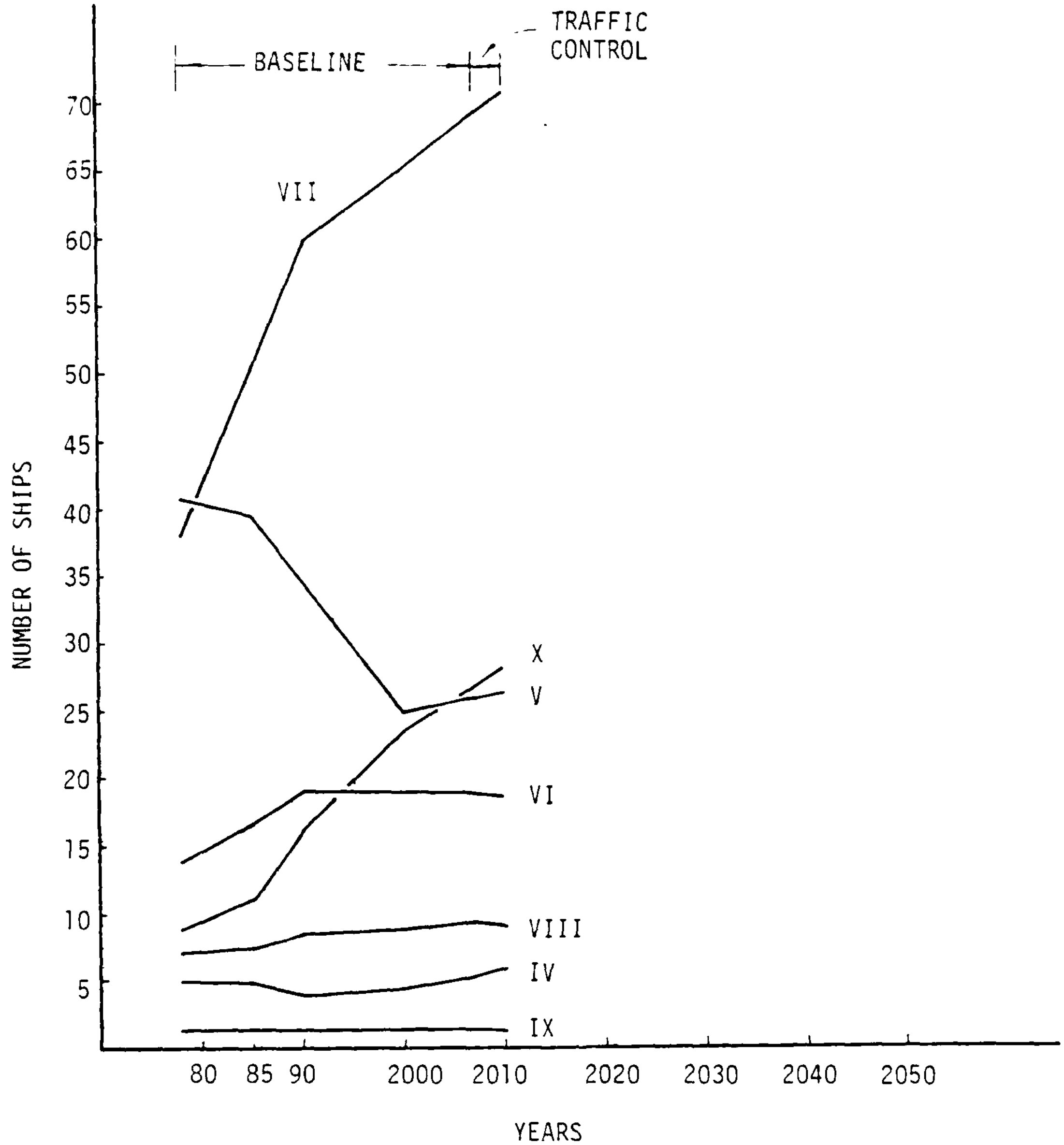

FIGURE 6.22 SOO FLEET MIX - TRAFFIC CONTROL SYSTEM

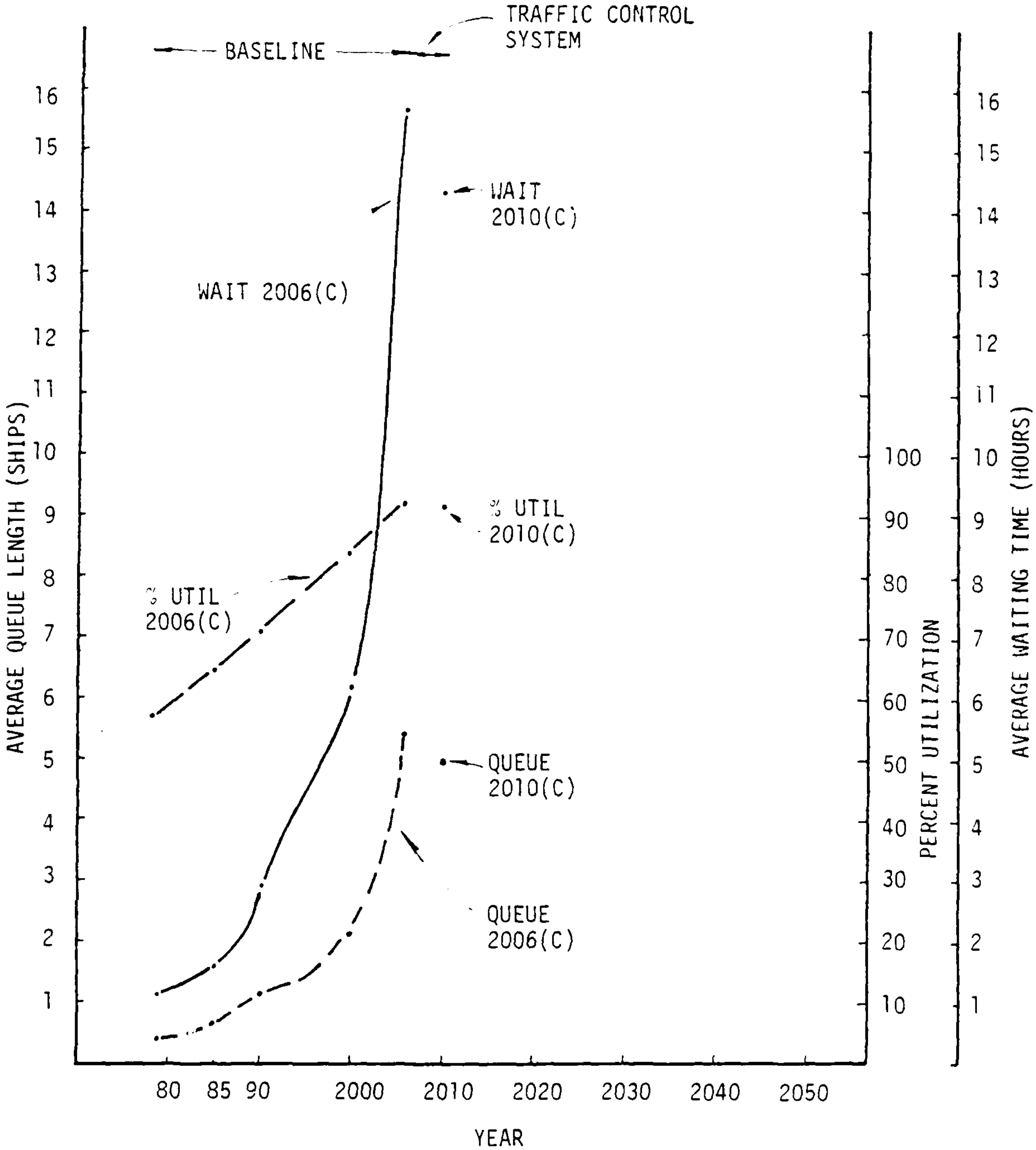

FIGURE 6.23 TRAFFIC CONTROL SYSTEM, POE LOCK - QUEUE LENGTH, WAITING TIME, % UTILIZATION; 25.5 FOOT DRAFT

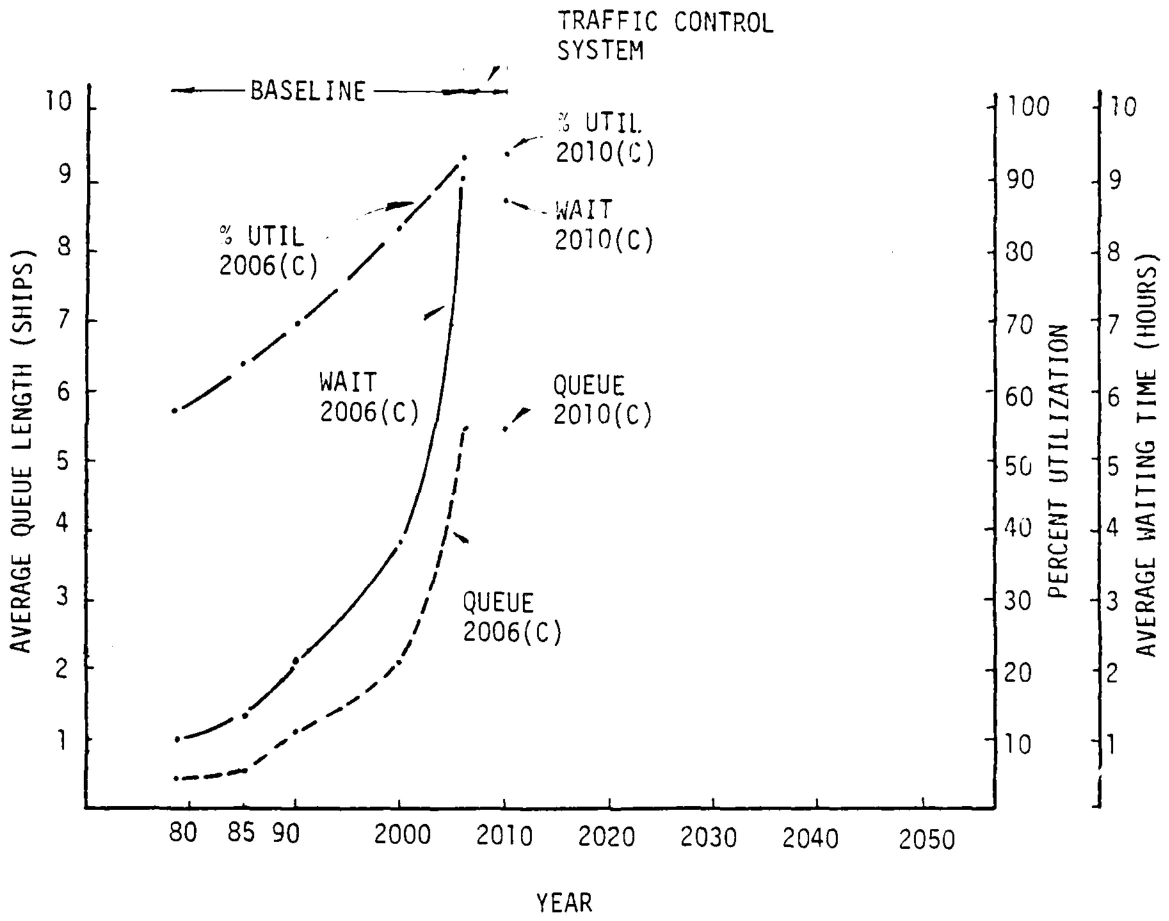

FIGURE 6.24 TRAFFIC CONTROL SYSTEM, MacARTHUR LOCK - QUEUE LENGTH WAITING TIME, % UTILIZATION; 25.5 FOOT DRAFT

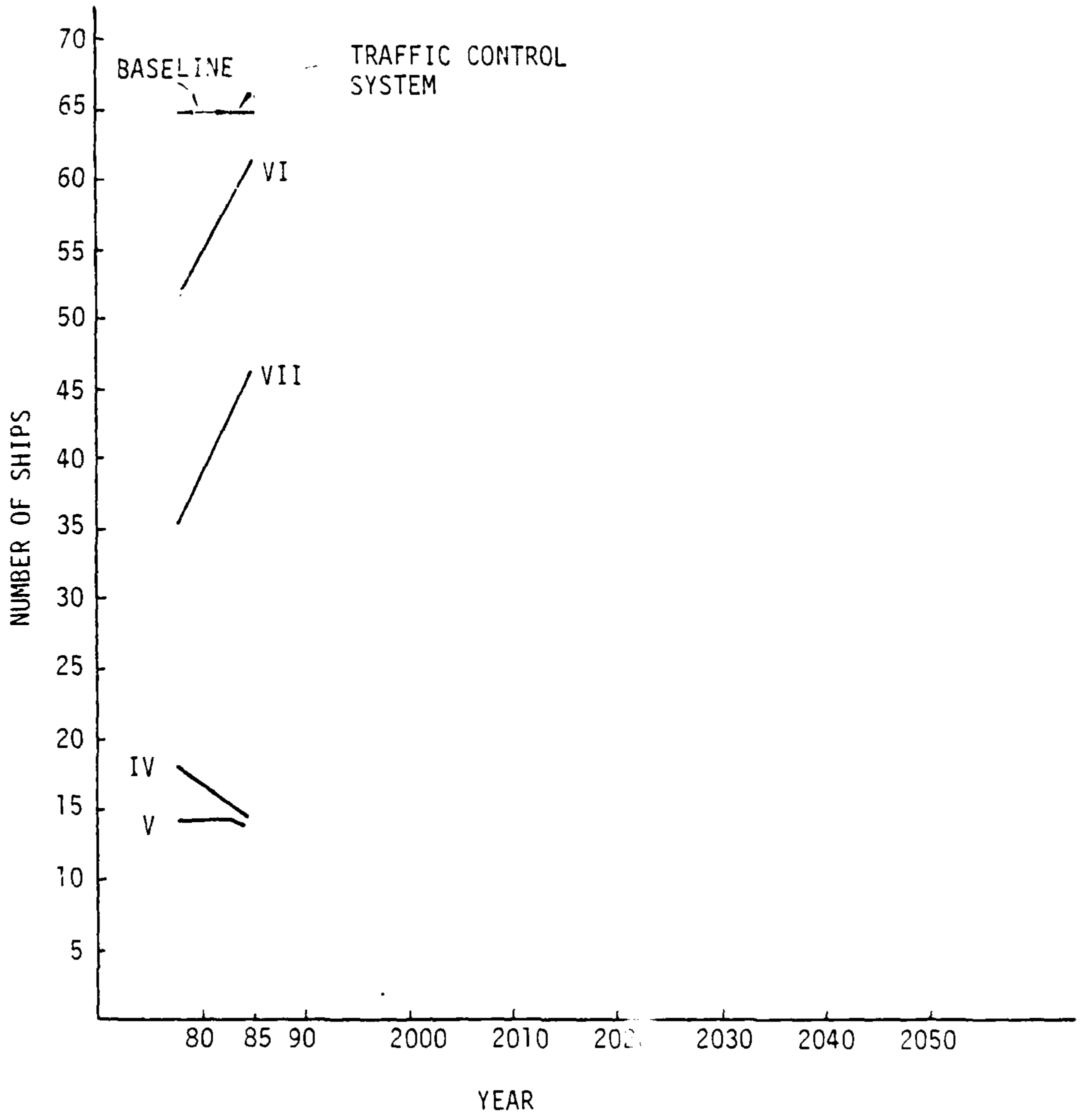

FIGURE 6.25 WELLAND CANAL FLEET MIX - TRAFFIC CONTROL SYSTEM

The total number of transits through the Welland Canal increased 3.1%, from 7,268 transits in 1981 to 7,496 transits in 1983. The ratio of loaded transits to total transits increased slightly from 64.7% in 1981 to 65.2% in 1983. Lock capacity increased slightly because of the reduction in the number of ballasted transits.

Lock utilization at the constraining lock on the Welland Canal at capacity in 1983 was an average of 94.9% over the peak months of May through November. During July, the most severe month, the lock utilization was greater than 98.0% , average vessel waiting time was 35.1 hours upbound and 34.6 hours downbound, and average queue length was 24.2 ships both upbound and downbound. The lock utilization, average vessel waiting time, and average queue length are shown on Figure 6.26.

6.5.2.3 St. Lawrence River - With the implementation of a traffic control system upon reaching capacity in 2006, capacity on the St. Lawrence River Locks was delayed until 2012. The amount of cargo processed through the St. Lawrence Locks at capacity in 2012 was 97,789,000 short tons. This is an increase of 5,263,000 short tons, or 5.7%, over the base case capacity in 2006 of 92,526,000 short tons.

Most of the tonnage increase through the St. Lawrence River from 2006 to 2012 was from other bulk, iron ore, and grain. Other bulk increased 7.5%, iron ore increased 6.3%, and grain increased 4.8%.

The total number of ships operating through the St. Lawrence River increased 17.6%, from 143.4 ships in 2006 to 161.0 ships in 2012. The composite ship class for the St. Lawrence River fleet remained constant at 6.1. No capacity increase was therefore realized from increased ship size. The St. Lawrence River fleet mix is shown on Figure 6.27.

The total number of transits through the St. Lawrence River Locks increased 12.7%, from 7,429 transits in 2006 to 8,373 transits in 2012. The percentage loaded transits remained constant from 2006 to 2012 at 70.0. Capacity was therefore not increased from reducing the percentage of ballasted transits.

At capacity in 2012 the constraining lock in the St. Lawrence River had an average lock utilization of 91.0% over the peak months of May through November. During July, the most severe month, lock utilization was greater than 98.0%, the average vessel waiting time was 30.0 hours upbound and 26.7 hours

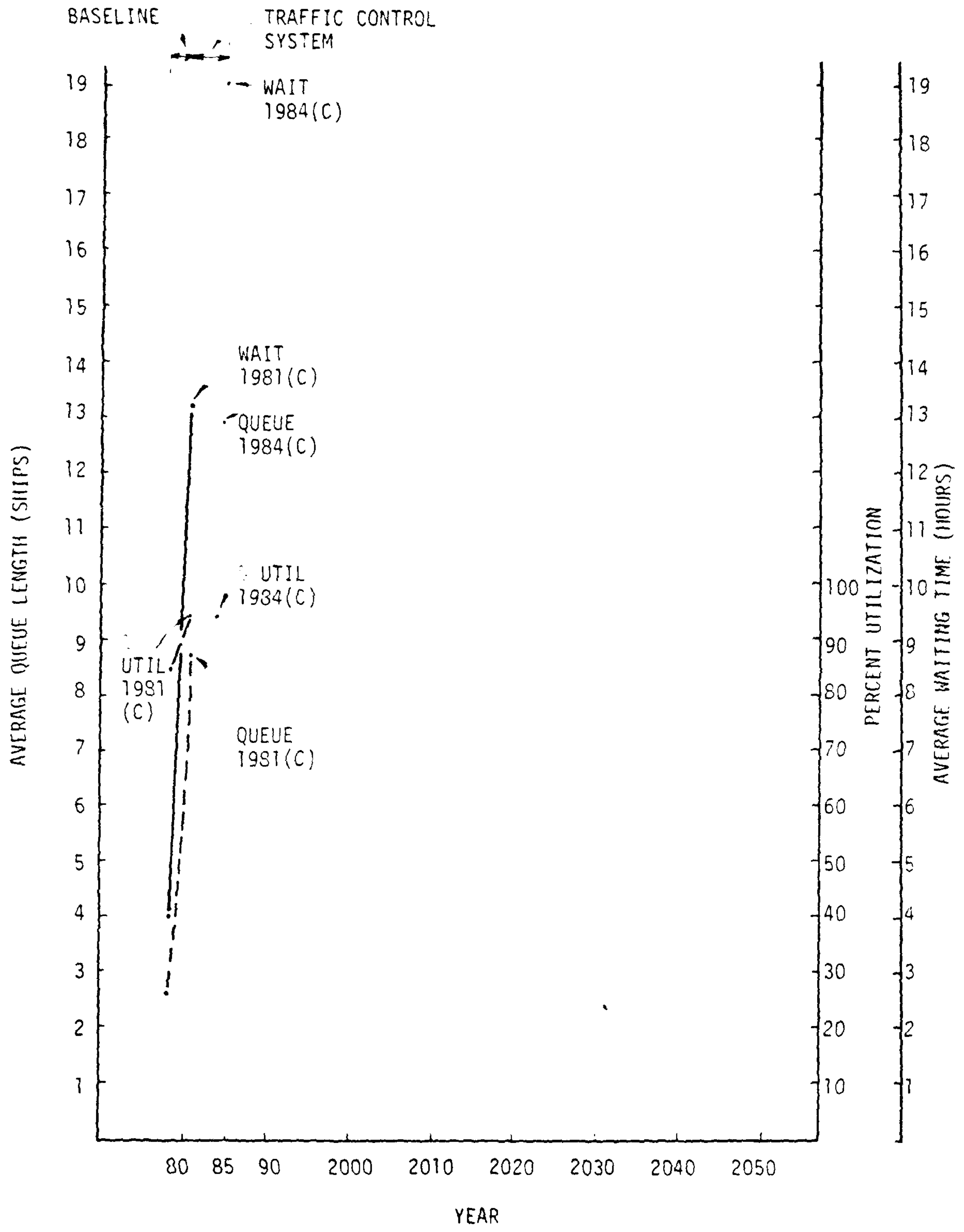

FIGURE 6.26 TRAFFIC CONTROL SYSTEM, WELLAND CANAL - QUEUE LENGTH, WAITING TIME, % UTILIZATION; 25.5 FOOT DRAFT

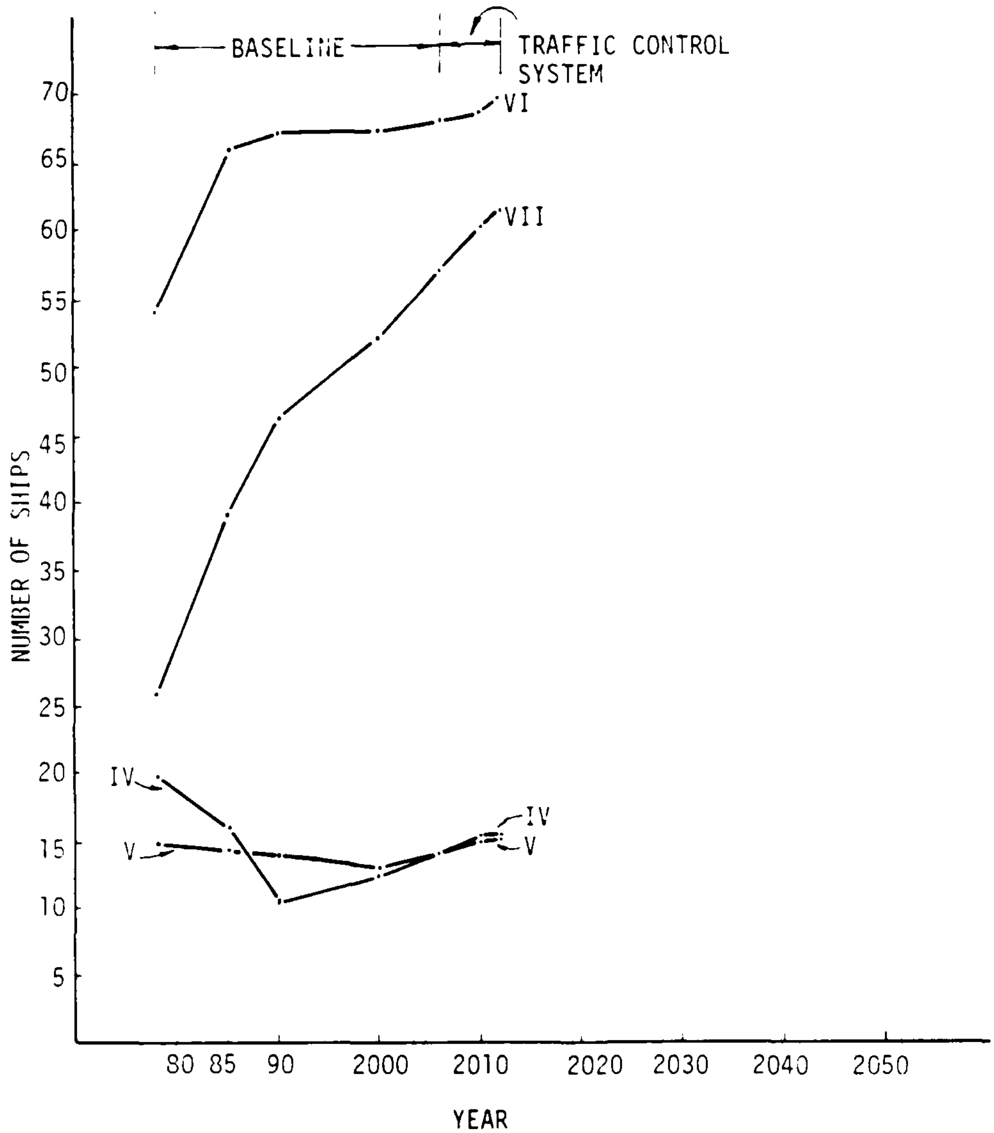

FIGURE 6.27 ST. LAWRENCE RIVER FLEET MIX - TRAFFIC CONTROL SYSTEM

downbound, and the average queue length was 24.2 ships upbound and 21.5 ships downbound. The lock utilization, average vessel waiting time, and average queue length for the constraining lock on the St. Lawrence River are shown on Figure 6.28.

6.6 Non-Structural Alternatives to Maximum Utility

6.6.1 Lock Improvement

The term "Non-Structural Alternatives to Maximum Utility" refers to the combination of the preceding non-structural alternatives selected in a way that shows potential for providing the greatest increase in lock system capability and that accounts for mutually exclusive contributions to lockage time reduction. For any given fleet level, capacity will be increased when ships can be processed through the system more quickly. Specifically, system effectiveness is a function of locking times.

The locking operation can be considered as a series of discrete events each of which requires a certain amount of time to perform. Each of the four non-structural alternatives reduces the time it takes to perform one event. Traveling kevels and increased ship speed reduce the entrance time. Reduced dump/fill times and downstream longitudinal hydraulic assistance decrease chambering time. The traffic control system reduces approach time.

Traveling kevels provide the largest capacity increase of all the individual non-structural alternatives and therefore were included in the non-structural improvements to maximum utility. Since the ship entering the exiting the lock will be under the control of the traveling kevels, the alternatives of increasing ship speed into the lock and downstream longitudinal hydraulic assistance are excluded as independent contributions toward the reduction of lockage time. The capacity gain from traveling kevels is greater than the gain for the combination of the alternatives of increased ship speed and downstream longitudinal hydraulic assistance.

The three remaining non-structural improvements of traveling kevels, reduce dump/fill times and traffic control systems are independent and may, therefore, all be implemented together. Since each reduces a different component of the locking time, their locking time improvements are additive. The combination of the three improvements have therefore been selected as the non-structural alternatives implemented to maximum utility.

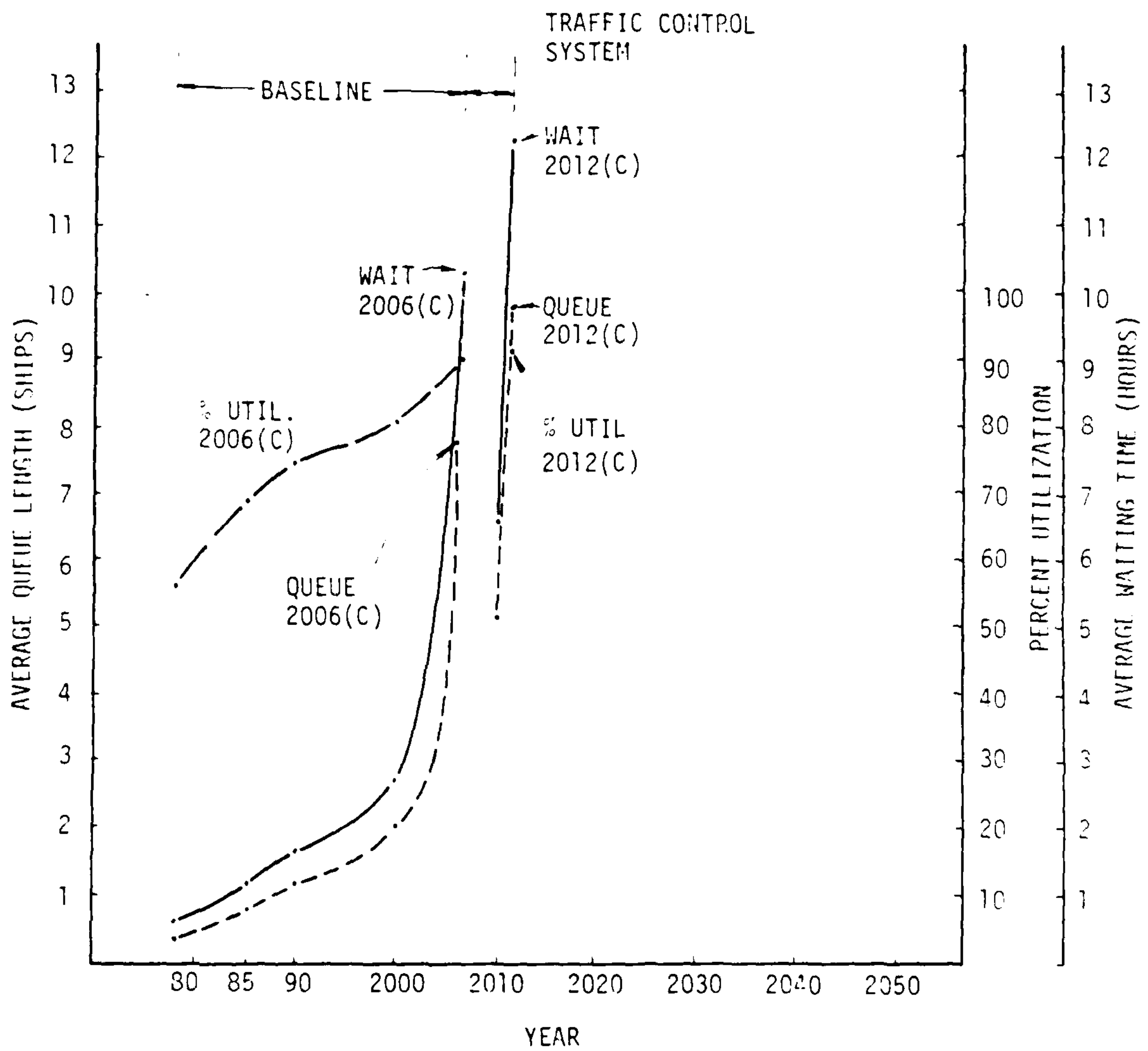

FIGURE 6.28 TRAFFIC CONTROL SYSTEM, ST. LAWRENCE RIVER, QUEUE LENGTH, WAITING TIME, % UTILIZATION; 25.5 FOOT DRAFT

At the Soo Locks, traveling kevels reduce locking time 7.5%, decreased dump/fill time reduces locking time 1.0%, and the traffic control system reduces locking time 4.5%. Implemented together, these alternatives reduce locking times at the Soo Locks by 13%.

At the Welland Canal, traveling kevels reduce locking time 7.5%, decreased dump/fill time decreases locking time 2.5%, and the traffic control system reduces locking time 3.0%. Implemented together, these alternatives reduce locking times at the Welland Canal by 13%.

At the St. Lawrence River Locks, traveling kevels reduce locking time 7.5%, decreased dump/fill time reduces locking time 1.0%, and the traffic control system reduces locking time 4.5%. Implemented together, these alternatives reduce locking times at the St. Lawrence River Locks by 13.0%.

6.6.2 <u>Results of Capacity Simulation</u>

6.6.2.1 <u>Soo Locks</u> - By implementing the non-structural improvements at the Soo Locks to maximum utility, the capacity condition was delayed from 2006 under base conditions to 2018. At capacity in 2018 the amount of cargo processed through the Soo Locks was 196,766,000 short tons. This is an increase of 23,072,000 short tons or 13.3% over the 173,739,000 short tons that passed through the Soo Locks in 2006.

Most of the increases in tonnage between 2006 and 2018 came in iron ore and grain. Iron ore increased 17.3%, and grain increased 9.3%.

The number of vessels in the fleet operating through the Soo Locks increased 9.7%, from 154.3 ships in 2006 to 169.3 ships in 2018. The composite ship class for the Soo fleet increased only slightly, from 7.0 in 2006 to 7.1 in 2018, indicating very little increase in lock capacity due to an increase in ship sizes. The Soo fleet mix from 1978 to 2018 is shown on Figure 6.29.

The total number of transits through the Soo Locks increased 9.1%, from 10,825 transits in 2006 to 11,806 transits in 2018. The ratio of loaded to total transits did not increase significantly between the 55.7% in 2006 and the 56.1% in 2018. Since the fleet size did not increase significantly and the percentage of empty transits was not reduced significantly, it can be concluded that almost all of the increase in tonnage capacity was gained from the 13% reduction in locking time due to implementing the non-structural alternatives.

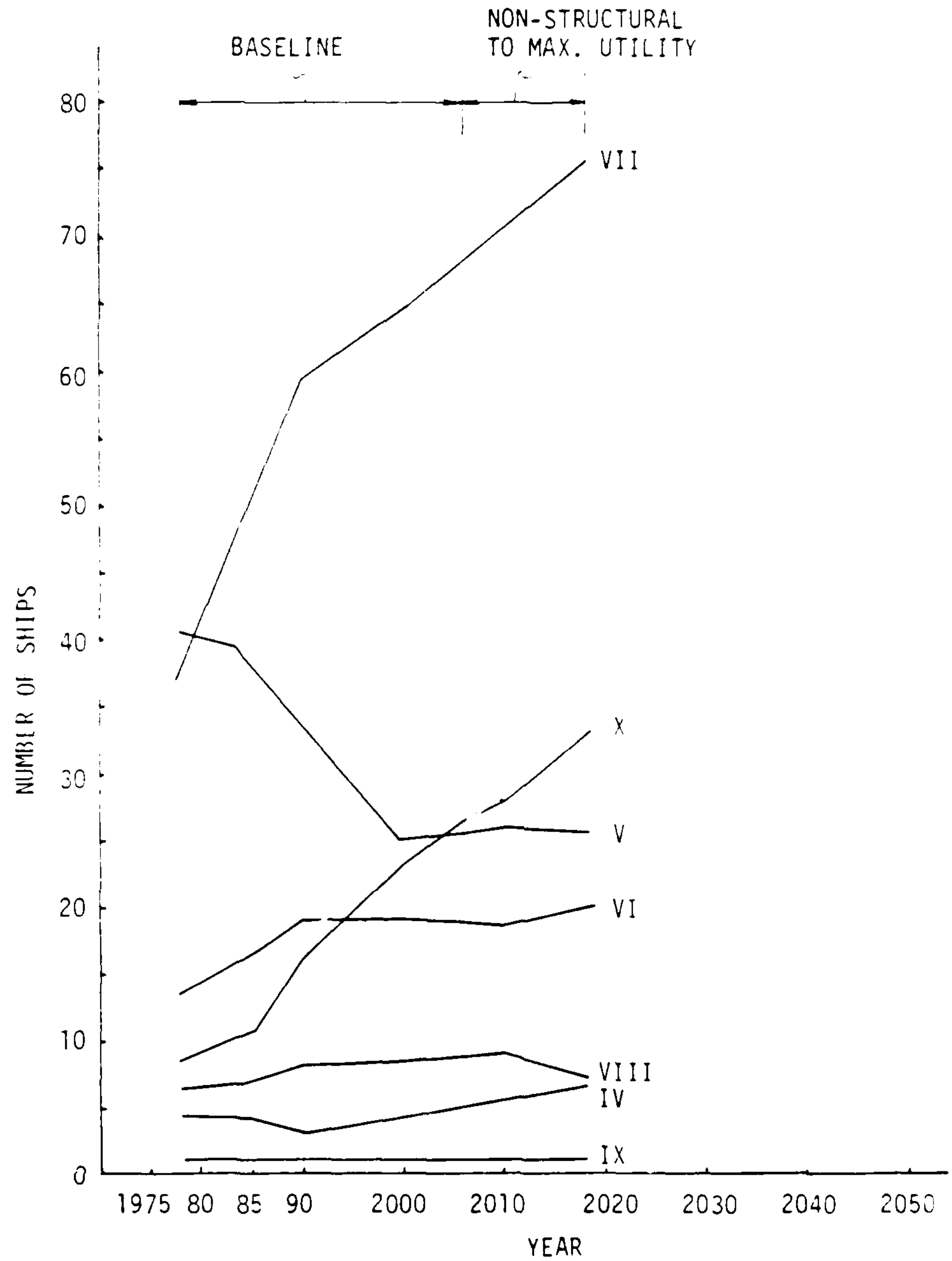

FIGURE 6.29 SOO FLEET MIX - NON-STRUCTURAL ALTERNATIVES TO MAXIMUM UTILITY

Capacity was reached at the Poe Lock in 2018. The Poe Lock had an average lock utilization during the peak months of May through November of 90.0%. During the most congested month, May, the lock utilization was 90%, the average waiting time was 3.9 hours upbound and 11.3 hours downbound, and the average queue length was 1.0 vessels upbound and 4.0 vessels downbound. The lock utilization, average vessel waiting time, and average queue length for the Poe Lock are given in Figure 6.30. The MacArthur Lock did not reach capacity for this period of time.

6.6.2.2 Welland Canal - After implementation of the non-structural alternatives to maximum utility at capacity in 1981, the Welland Canal reached capacity again in 1996. At capacity in 1996 a total of 88,598,000 short tons of cargo were processed through the Welland Canal. This is an increase of 13,400,000 short tons or 17.8% over the 75,198,000 short tons processed through the Welland Canal at capacity in 1981.

The major increases in cargo came in other bulk, iron ore, and grain. Other bulk increased 22.4%, iron ore increased 21.3%, and grain increased 17.4%.

The number of ships in the Welland Canal fleet increased 12.7%, from 130.4 ships in 1981 to 147.0 ships in 1996. The composite ship class for the Welland Canal fleet increased somewhat from 6.0 to 6.2; however, major increases in composite iron ore and coal ship classes occurred. The composite iron ore ship increased from 6.1 to 6.8 and the composite coal ship increased from 6.0 to 6.8. The Welland Canal fleet mix is shown on Figure 6.31.

The total number of transits through the Welland Canal increased 11.1% from 7,268 transits in 1981 to 8,075 transits in 1996. However, the percent loaded transits decreased from 64.7% in 1981 to 63.9% in 1996, causing a slight decrease in capacity.

Lock utilization at the constraining lock on the Welland Canal at capacity in 1996 was an average of 91.7% during the peak months of May through November. During July, the most severe month, lock utilization was 97%, average waiting time was 19.1 hours upbound and 9.8 hours downbound, and average queue length was 14.4 vessels upbound and 7.4 vessels downbound. The lock utilization, average waiting time, and average queue length for the Welland Canal are shown on Figure 6.32.

6.6.2.3 St. Lawrence River - With implementation of the non-structural alternatives to maximum utility, capacity was reached in the St. Lawrence River Lock System in 2024. The amount of cargo processed through the locks at capacity in 2024

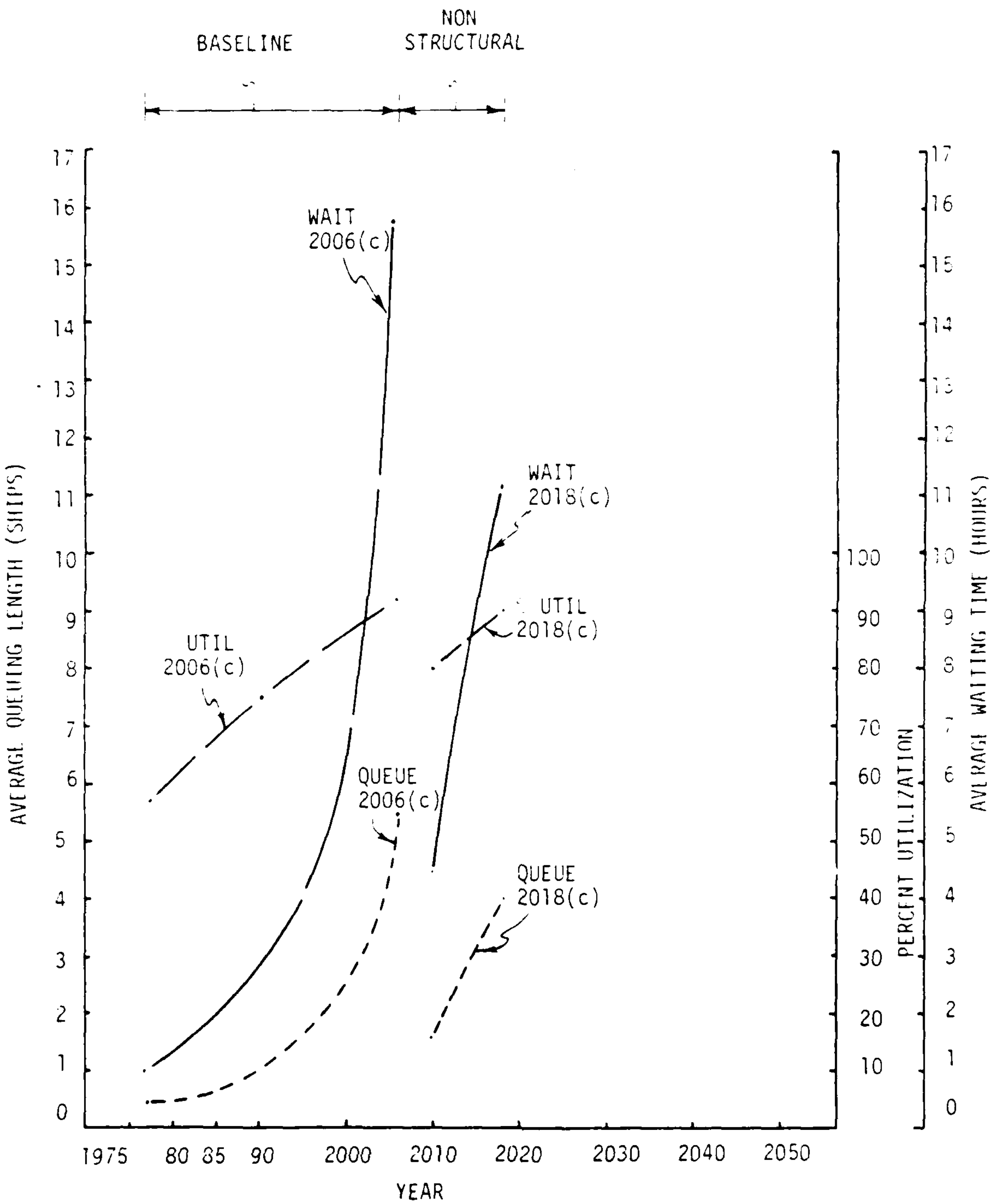

FIGURE 6.30 POE LOCKS - NON-STRUCTURAL ALTERNATIVES TO MAXIMUM UTILITY; QUEUE LENGTH, WAITING TIME, AND UTILITY

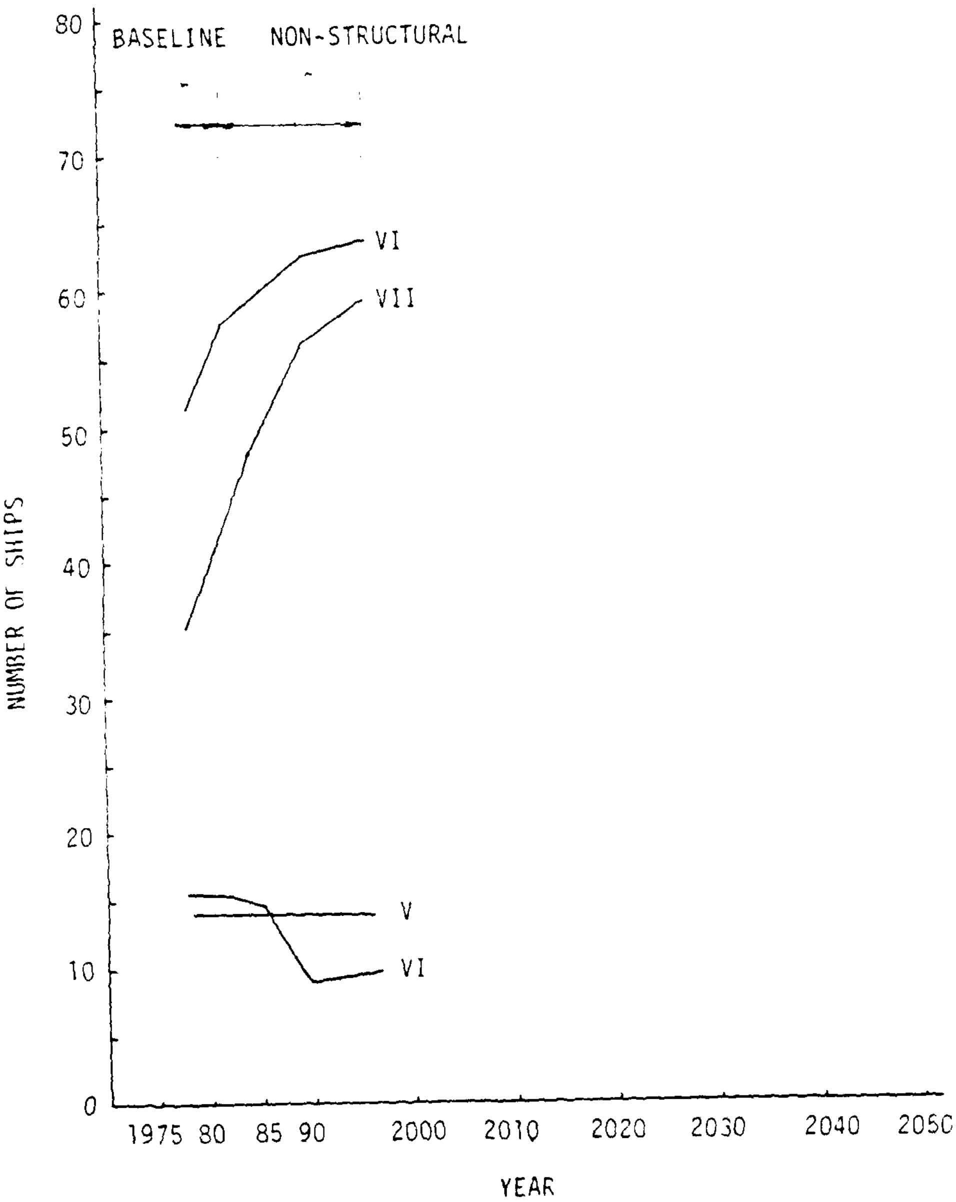

FIGURE 6.31 WELLAND CANAL FLEET MIX - NON-STRUCTURAL ALTERNATIVES TO MAXIMUM UTILITY

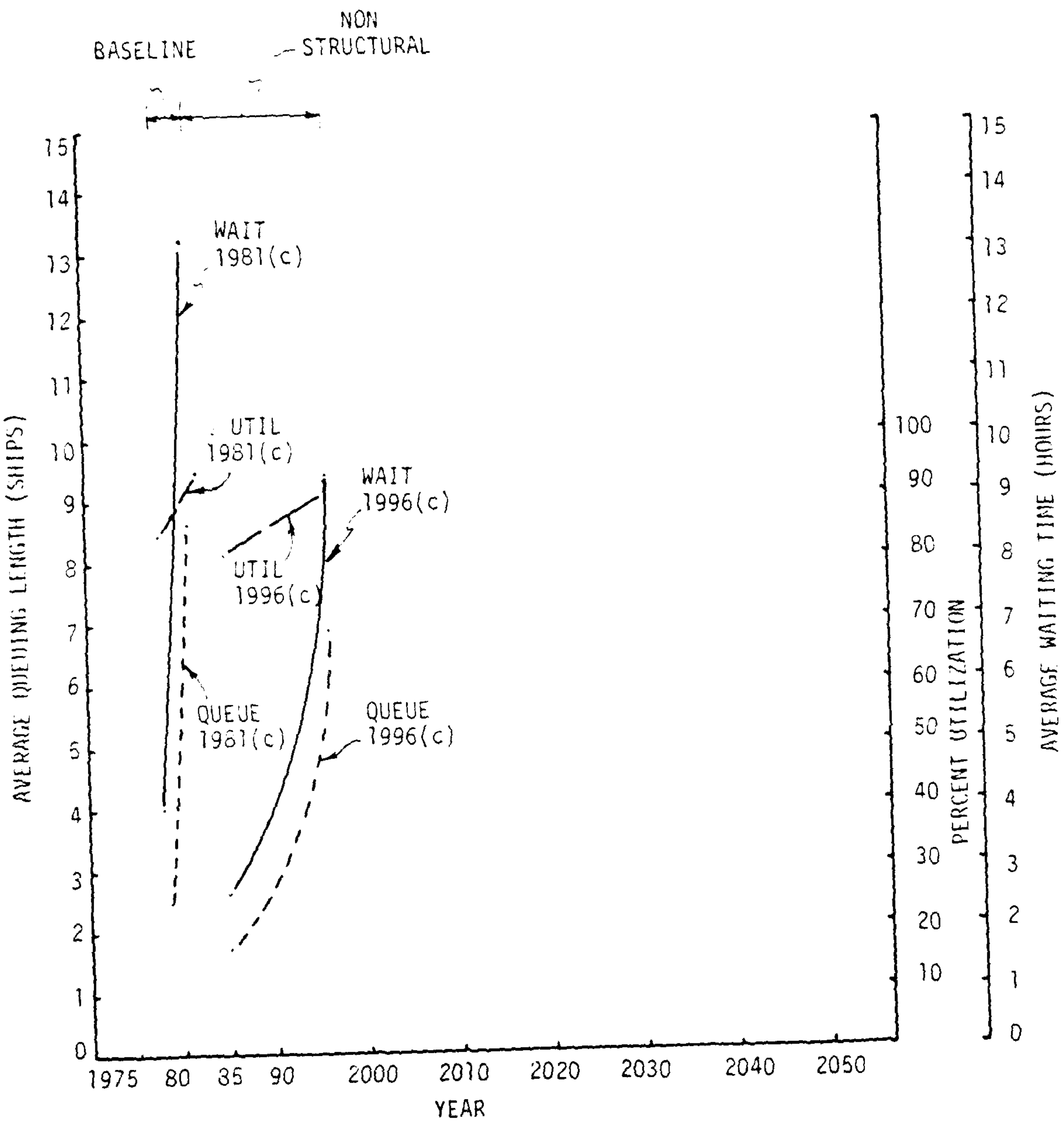

FIGURE 6.32 WELLAND CANAL - NON-STRUCTURAL ALTERNATIVES TO MAXIMUM UTILITY; QUEUE LENGTH, WAITING TIME, AND UTILIZATION

was 108,597,000 short tons. This is an increase of 16,071,000 short tons or 17.4% over the base case capacity in 2006 of 92,526,000 short tons.

Most of the tonnage increase was in other bulk, iron ore, and grain. Other bulk increased 24.8%, iron ore increased 19.4%, and grain increased 14.1%.

The total number of ships in the St. Lawrence River fleet increased 25.0%, from 143.4 ships in 2006 to 179.2 ships in 2024. The composite ship class remained constant at 6.1 from 2006 to 2024, indicating that the overall fleet size did not change with time. No additional capacity was realized through the construction of larger ships. The St. Lawrence River fleet mix is shown on Figure 6.33.

The total number of transits through the St. Lawrence River Locks increased 25.8%, from 7,429 transits in 2006 to 9,345 transits in 2024. The ratio of loaded to total transits remained constant from 2006 to 2024. Both the composite ship size and the loaded to total transit ratio remained constant, indicating that the entire capacity expansion was gained through the decreased locking times.

In 2024 the constraining lock in the St. Lawrence River had an average lock utilization of 93.0% over the peak months of May through November. During July, the most severe month, lock utilization was greater than 98%, the average vessel waiting time was 27.3 hours upbound and 27.5 hours downbound, and the average queue length was 24.2 ships upbound and downbound. The lock utilization, average waiting time, and average queue length for the constraining lock on the St. Lawrence River are shown on Figure 6.34.

6.7 Summary of the Impact of Non-Structural Alternatives on Lock Capacity

Subsections 6.2 through 6.6 of this report discussed in detail the impact of each non-structural alternative on lock system capacity. Fleet mix and queuing information for each lock system and each alternative were presented both graphically and in the text. This section summarizes the results of these analyses and discusses the capacity relief generated by the alternatives.

Several parameters can be used to indicate the effectiveness of implementing a capacity expansion measure. As an overall

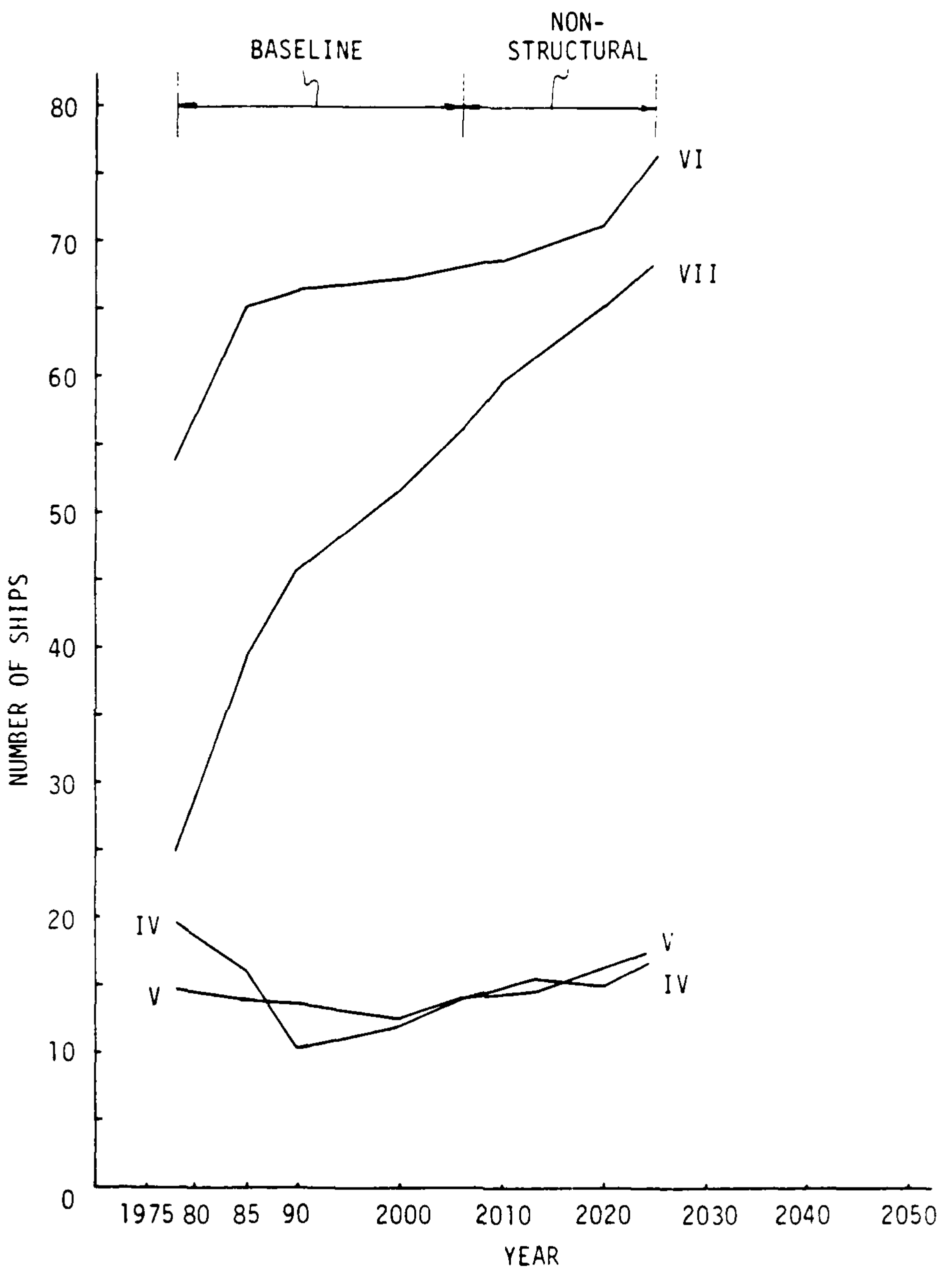

FIGURE 6.33 ST. LAWRENCE RIVER FLEET MIX - NON-STRUCTURAL ALTERNATIVES TO MAXIMUM UTILITY

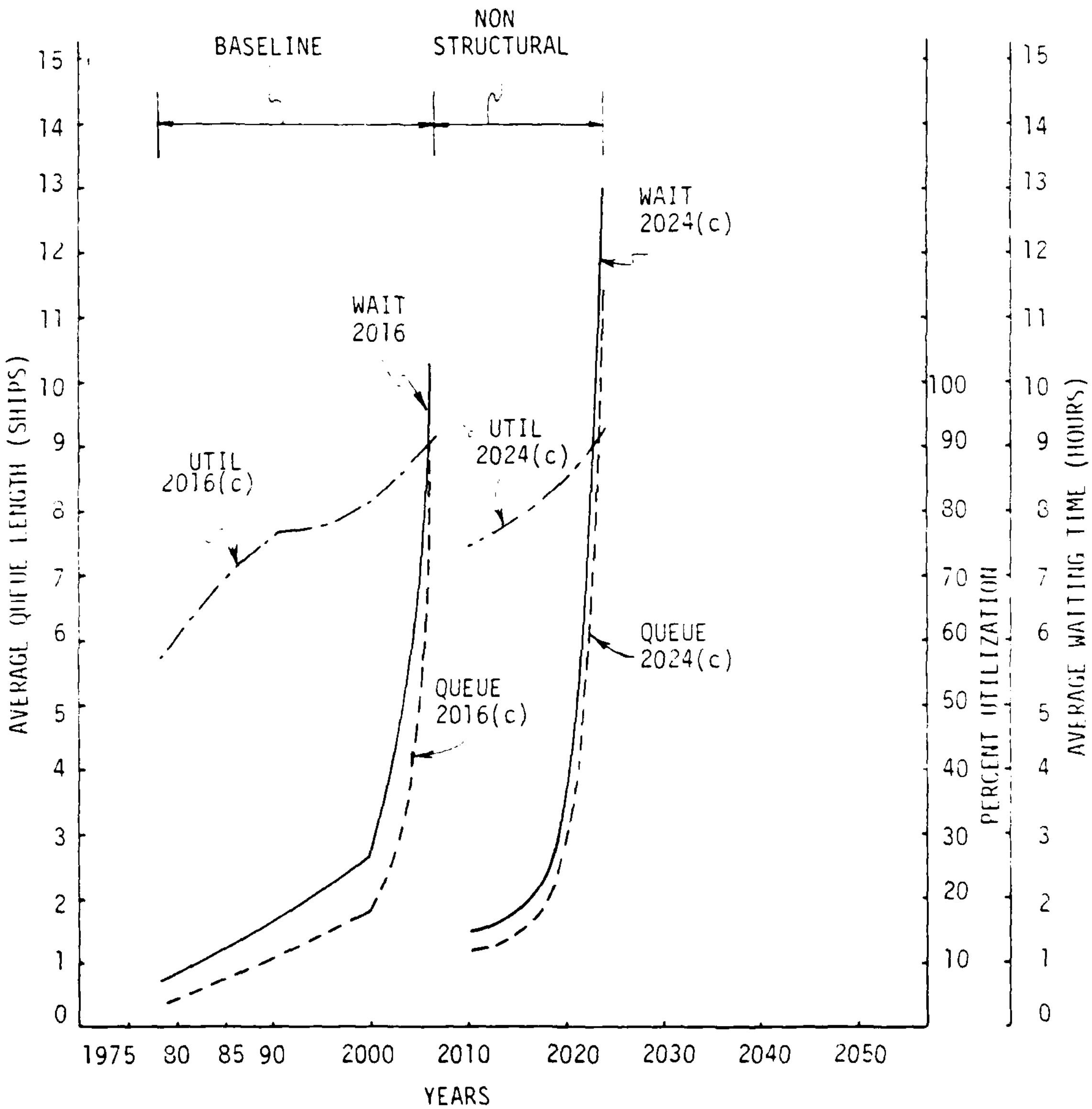

FIGURE 6.34 ST. LAWRENCE RIVER - NON-STRUCTURAL ALTERNATIVES MAXIMUM UTILITY; QUEUE LENGTH, WAITING TIME, AND UTILITY

indicator of effectiveness, the additional cargo tonnage processed through the locks as a result of implementing the expansion measure may be the most useful. Lock operators may use the increase in the number of transits per day through the lock resulting from implementing a capacity expansion measure as an indicator of effectiveness because ballasted ships require as much effort to lock through as loaded ships. Fleet operators might measure the effectiveness of a capacity expansion alternative by the reduction in vessel waiting time the alternative provides.

Waiting time reductions due to capacity expansion measures are temporary. As the demand for service grows and the capacity of the lock system is again approached, waiting times will increase to the same levels that existed before the measure was implemented. However, in the interim, the system has served its customers effectively at below-capacity conditions. Tonnage and number of transits are permanent gains provided by the capacity expansion measures. Therefore, these two parameters are used in this summary as a basis for comparing the non-structural alternatives. Tonnage and the number of transits at capacity for each of the non-structural alternatives are summarized in Table 6.2. Waiting times were shown graphically on the queuing information figures that accompany the discussion of the capacity analyses for each alternative.

It can be seen from Table 6.2 that traveling kevels have the best gains in tonnage, number of transits, and years until capacity is again reached at all of the locks compared to the other individual non-structural alternatives. This is to be expected since traveling kevels would reduce locking times more than any of the other alternatives considered in this study.

From Table 6.2 it can be seen that the remaining individual non-structural alternatives rank in different positions at each lock system. Decreasing the lock chambering time and the local traffic control system rank identically second at the Soo. Increasing the ship speed into the locks is the second best alternative in terms of capacity increase at the Welland Canal. At the St. Lawrence River, the local traffic control system yields the second best capacity improvement of the individual alternatives considered.

Implementing the non-structural alternatives to maximum utility, consisting of installing traveling kevels, decreasing the lock dump/fill times, and installing a local traffic control system can provide a greater increase in capacity than is achieved by any of the individual non-structural alternatives.

TABLE 6.2 NON-STRUCTURAL ALTERNATIVES EFFECTIVENESS SUMMARY

NON-STRUCTURAL	SOO			WELLAND CANAL			ST. LAWRENCE RIVER		
	CAPACITY YEAR	TONNAGE AT CAPACITY (10^3 ST)	TRANSITS AT CAPACITY	CAPACITY YEAR	TONNAGE AT CAPACITY (10^3 ST)	TRANSITS AT CAPACITY	CAPACITY YEAR	TONNAGE AT CAPACITY (10^3 ST)	TRANSITS AT CAPACITY
Base Case	2006	173,739	10,825	1981	75,198	7,268	2006	92,526	7,910
Traveling Kevels	2014	189,501	11,517	1985	80,738	7,627	2016	100,534	8,597
Increase Ship Speed Entering Locks	2008	177,988	11,041	1984	78,921	7,497	2010	96,198	8,247
Decrease Lock Chambering Time	2010	182,250	11,247	1983	78,839	7,496	2010	96,353	8,246
Local Traffic Control System	2010	182,250	11,246	1983	78,735	7,496	2012	97,789	8,373
Non-Structurals to Maximum Utility	2018	196,766	11,807	1996	88,598	8,075	2024	108,597	9,345

However, the total increase in tonnage at capacity is less than the sum of the tonnage increases for the individual alternatives. This is due to the fact that the individual alternative lockage time improvements are not additive for the non-structurals to maximum utility case and because other factors besides locking time also affect lock system capacity.

7. ANALYSIS OF STRUCTURAL ALTERNATIVES

7.1 Introduction

Structural alternatives for increasing lock capcity consist of constructing new, larger locks or increasing the depth of existing locks and channels. In this study five structural scenarios were tested to determine the sensitivity of their effects on GL/SLS System capacity. The five scenarios specified by the Corps of Engineers [8] are as follows:

1. Operate 1350 x 115 foot locks after the system has reached capacity with the non-structurals to maximum utility.

2. Operate 1460 x 145 foot locks after the system has reached capacity with the non-structurals to maximum utility.

3. Allow 28 foot ship draft after the system reaches capacity with the non-structurals to maximum utility.

4. Allow 32 foot ship draft after system reaches capacity with the non-structurals to maximum utility.

5. Limit cargo on the basis of a capacity condition with non-structurals to maximum utility at the Welland Canal. Operate a 1350 x 115 ft lock at the Soo when it reaches capacity.

The first two scenarios tested the effect of larger and wider ships on the capacity of the GL/SLS System. In Scenario 1 locks capable of handling 1100 x 105 foot (Class 11) ships were built at each of the three lock systems. These locks were placed in service when capacity was reached with the non-structurals to maximum utility alternative described in the previous section. Scenario 2 tested the same conditions except that the new locks were sized to handle 1200 x 130 foot (Class 12) ships.

The next two scenarios tested the effect of deeper ship draft on lock capacity. First, the existing locks were brought to capacity with non-structural alternatives implemented to maximum utility. Capacity was then increased again by allowing

ship drafts of 28 feet in Scenario 3 and 32 feet in Scenario 4 without a change in maximum allowable ship size.

The last scenario tested the effect of making structural modifications to the Soo Locks while the St. Lawrence Seaway Locks, including the Welland Canal, were not changed. New cargo projections were prepared by the Corps of Engineers [10] based on the Welland Canal reaching capacity with non-structural alternatives to maximum utility in 1996. The tonnage through the Welland Canal was held constant at the 1996 capacity tonnage, and the Soo and St. Lawrence River tonnages were adjusted accordingly. For this analysis, a 1350 by 115 foot lock, capable of handling Class 11 ships, was placed in operation at the Soo after capacity was reached using non-structural alternatives to maximum utility for the constrained cargo. Only non-structural improvements were implemented at the Welland and St. Lawrence River Locks.

7.2 Fleet Mix for Structural Alternatives

This section estimates shipbuilding trends to meet proposed structural changes to existing GL/SLS locks systems. As was done in the base case, past shipbuilding customs and commodity projections were used to estimate the perdent of each class of ship that would be built. In addition, leading shipping industry representatives were consulted. In particular, we are deeply indebted for the assistance provided by David Buchanan, Vice President of the Lake Carriers Association, and to John Greenwood, author of "Greenwood's Guide to Great Lakes Shipping".

Structural changes to existing locks systems that will affect the fleet are basically building larger locks. Given a larger lock system, one must then determine the extent to which fleet operators will acquire the largest classes of ships that can use these systems. This study analyzes the feasibility of structural change alternatives; one that would permit the use of 1100 foot ships and a second that would permit the use of 1200 foot ships. It is therefore necessary to establish a fleet expansion model that will reflect the way in which fleet operators will respond to these expansions in the physical size of the locks.

Considering the question of building ships 1100 and 1200 feet long, industry representatives do not believe that fleet

operators will go the larger ships as they did the 1000 footers. There is no present demand for larger ships, therefore industry representatives do not believe that the larger ships will be built. Historically operators have built larger ships as larger locks became available; however, this pattern may change because of the increased capital costs of large ships. The cost of a 1000 footer has gone up from 35 to 70 million dollars in the past five years. Fleet operators may determine that the cost of a 1100 or 1200 footer is so high that the ships would not be justified by the additional cargo they could carry [11]. There are other reasons why the shift to Class 11 and 12 ships may be somewhat restrained. These include:

- Size of dry docks
- Design strength of ships
- Reach of shoreside machinery
- Service facilities of commodity terminals.

The first 1000 foot laker was constructed and placed in service in 1972, just four years after completion of the Poe Lock in 1968. Since that time the size of the 1000 foot fleet has increased dramatically. At this writing (May 1981), there are thirteen 1000 foot lakers listed in "Greenwood's Guide to Great Lakes Shipping". There are, however, no new 1000 foot vessels on order, and unless current trends in commodity demand change, there will be no additional new ship construction for the U.S. flag dry bulk cargo fleet for at least two years (1983). Only modest growth in cargo is expected through the middle of the decade or until the rebuilding of the U.S. steel industry is in full swing [12].

These comments are presented in justification of the plan for the fleet expansion presented in this analysis. The GL/SLS System capacity expansion scenarios used in this study call for increases in lock size to accommodate 1100 foot and 1200 foot ships. Based on expected shipbuilding trends, the fleet mix model used in these scenarios shows fleet expansion in the largest classes of ships, but not at the rate that 1000 foot ships were built between 1972 and 1981. Future expansion into the largest classes of ships is expected to be somewhat slower. Tables 7.1, 7.2, and 7.3, showing the expected fleet expansion patterns for the 1100 foot vessel scenario, reflect this thinking. The paragraphs that follow the tables describe some of the special conditions that were considered to determine the percent growth in each ship class. Tables 7.4 and 7.5 show

TABLE 7.1 SOO LOCKS FLEET GROWTH
STRUCTURAL ALTERNATIVE 1 - GL/SLS LOCKS SYSTEMS
EXPANDED TO ACCEPT SHIPS 1100 FEET LONG BY 105 FEET WIDE

CLASS	ORE	COAL	STONE	GRAIN	OTHER BULK	GENERAL CARGO
4	0	0	0	0	30	10
5*	10	5	40	5	60	10
6**	0	5	0	10	0	30
7	0	10	60	5	10	0
8	10	5	0	0	0	50
9	0	0	0	0	0	0
10	60	65	0	60	0	0
11	20	10	0	20	0	0

* Class 5 and 6 lakers
** Ocean class

- Ore - Class 5 and 6 lakers will continue to be built because of port restrictions. Ocean Class 6 will not handle ore. Class 7 ships will tend to drop off because both the Welland and St. Lawrence River will handle 1100 foot ships. Class 8 ships will continue to be added to meet specific port situations. New growth for ore will be mostly Class 10 and 11 with more Class 10's being added because high capital costs may not justify adding a higher proportion of Class 11 ships.

- Coal - Some coal will continue to be carried in Class 5, 6, and 8 ships because of special port situations. Class 7 ships will continue to be used by Canadian operators. The greatest number of ships added will be for Class 10 and 11, and as in the case of ore, the greatest number of large ships will be Class 10.

- Stone - Stone is not carried by the largest ships and is not carried by foreign ships. Expansion in stone capacity is therefore split between laker Classes 5, 6, and 7.

- Grain - Some grain is expected to continue to be shipped in laker Class 5 and 6 ships shown here as Class 5. Some grain is currently shipped in foreign vessels and this practice is expected to continue. When significant increases in the demand for grain occur, grain is expected to be carried in the largest ships. This grain may be carried to the mouth of the St. Lawrence River for shipment overseas. Although loading facilities for Class 10 and 11 grain carriers do not presently exist, it is likely they would be developed to meet a significant increase in demand.

- Other Bulk - These cargos will go in smaller ships, but not in ocean class ships. If demand increases, some larger ships may be added.

- General Cargo - Traffic will continue in salties and smaller lakers, with growth, as it occurs in Class 8.

TABLE 7.2 WELLAND CANAL FLEET GROWTH
STRUCTURAL ALTERNATIVE 1 - GL/SLS LOCKS SYSTEMS
EXPANDED TO ACCEPT SHIPS 1100 FEET LONG BY 105 FEET WIDE

CLASS	ORE	COAL	STONE	GRAIN	OTHER BULK	GENERAL CARGO
4	0	0	25	0	20	10
5*	0	0	5	0	30	10
6**	10	5	10	15	30	40
7	10	35	60	5	20	5
8	0	10	0	0	0	30
9	0	0	0	0	0	5
10	60	40	0	60	0	0
11	20	10	0	20	0	0

* Class 5 and 6 lakers
** Ocean class

- Ore - When the locks are expanded, ore shipments in laker Class 5 and 6 are expected to drop. Some foreign ships will continue to be used as will some Class 7 ships for special port situations. Capacity for additional demand, however, will be met by new Class 10 and 11 ships.

- Coal - Coal shipments will continue in Class 7 and 8 ships to meet port restrictions. If heavy demand for coal develops in the lakes, fleet operators can be expected to go to Class 10 and 11 ships.

- Stone - Stone is relatively minor commodity that presently moves in smaller ships. If demand increases, some stone may go in Class 7 ships, but it is not likely to go in larger ships.

- Grain - Currently grain is carried in Class 7 ships. If the locks expand and demand remains high, grain fleets can be expected to shift to the largest ships.

- Other Bulk - There is presently a large amount of coke going in foreign ships to the U.S. Most commodities represented in other bulk are minor and therefore these cargos are not expected to shift to larger ships.

- General Cargo - A large part of the general cargo is foreign steel coming to ports in the U.S. Therefore a large portion of general cargo growth is taken in ocean class ships with some expectation of expanding into larger ships.

TABLE 7.3 ST. LAWRENCE RIVER FLEET GROWTH
STRUCTURAL ALTERNATIVES 1 - GL/SLS LOCKS SYSTEMS
EXPANDED TO ACCEPT SHIPS 1100 FEET LONG BY 105 FEET WIDE

CLASS	ORE	COAL	STONE	GRAIN	OTHER BULK	GENERAL CARGO
4	0	0	10	0	20	10
5*	0	0	20	0	30	10
6**	10	5	40	15	30	40
7	10	45	30	5	20	5
8	0	0	0	0	0	30
9	0	0	0	0	0	5
10	60	40	0	60	0	0
11	20	10	0	20	0	0

* Class 5 and 6 lakers
** Ocean class.

- Ore - Ore shipments are the same as for the Welland Canal.
- Coal - Most coal comes from the U.S. to Lake Ontario. Coal ships in the SLR may be slightly smaller.
- Stone - Some foreign stone moves from overseas to Canada and the U.S. Stone will generally be carried in smaller ships and in ocean class.
- Grain - Grain traffic in SLR is the same as in the Welland Canal.
- Other Bulk/General Cargo - Same as for the Welland Canal.

TABLE 7.4 SOO LOCKS FLEET GROWTH
STRUCTURAL ALTERNATIVE 2 - GL/SLS LOCKS SYSTEMS
EXPANDED TO ACCEPT SHIPS 1200 FEET LONG BY 130 FEET WIDE

CLASS	ORE	COAL	STONE	GRAIN	OTHER BULK	GENERAL CARGO
4	0	0	0	0	30	10
5*	10	5	40	5	60	10
6**	0	5	0	10	0	30
7	0	10	60	0	10	10
8	10	5	0	0	0	30
9	0	5	0	0	0	10
10	30	50	0	50	0	0
11	10	5	0	10	0	0
12	40	15	0	25	0	0

* Class 5 and 6 lakers
** Ocean class

- Ore - Some Class 5, 6 and 8 ships will be built because of port restrictions. Ore shipments will tend to move toward the largest ships but not completely because of the high capital costs of the Class 11 and 12 ships.

- Coal - Some smaller coal ships will continue to be built because of port restrictions. If the demand for coal increases significantly, particularly for overseas shipments, fleet operators will add larger ships.

- Stone - Demand for stone is not expected to increase to the extent that large ships would be required.

- Grain - Some Class 5 and 6 lakers and ocean Class 6 would continue to haul grain, but if locks increase in size, grain demand is expected to move fleet operators to the largest ships. This also assumes that grain loading facilities would be developed for large class ships. Currently grain elevators service 730 x 76 foot ships.

- Other Bulk - These cargos go in smaller ships, but not ocean class.

- General Cargo - Package freight will continue to go in the smallest vessels. A large percent of general cargo will continue to be carried in ocean class. As demand increases, the size of general cargo vessels is expected to increase somewhat.

TABLE 7.5 WELLAND CANAL AND ST. LAWRENCE RIVER FLEET GROWTH, STRUCTURAL ALTERNATIVE 2 - GL/SLS LOCKS SYSTEMS EXPANDED TO ACCEPT SHIPS 1200 FEET LONG BY 130 FEET WIDE

CLASS	ORE	COAL	STONE(SLR)***	GRAIN	OTHER BULK	GENERAL CARGO
4	0	0	25(10)	0	10	10
5*	0	0	5(20)	0	15	10
6**	10	5	10(40)	15	20	20
7	10	35	60(30)	5	20	10
8	0	10	0	0	20	30
9	0	0	0	0	15	20
10	30	20	0	30	0	0
11	30	20	0	30	0	0
12	20	10	0	20	0	0

* Class 5 and 6 lakers
** Ocean class
*** All predictions are the same for the Welland and SLR except for stone. Most of the stone is carried from Lake Ontario through the Welland Canal to the U.S.

- Fleet growth rates follow the same general pattern as shown for the Soo in Table 7.4 except there is less demand for laker Class 5 and 6 ships for ore, coal, and grain.

- Class 8 and 9 may also include some ocean-going ships longer than 700 feet which can utilize the Seaway due to its increased width.

the expected fleet expansion patterns for the 1200 foot vessel scenario. Table 7.6 shows the expected fleet expansion patterns for the Soo locks with cargo constrained by the Welland Canal and 1100 foot vessels at the Soo. Table 7.7 contains the Welland Canal and St. Lawrence River fleet mix building factors for the constrained case.

7.3 Lockage Times for Structural Alternatives

7.3.1 Introduction

Modeling 1100 and 1200 foot locks requires that new locking times be predicted based on current experience and engineering estimates. This section describes the methods that were used to develop these times.

Two assumptions were used in the development of locking time data:

- The relationships between the existing data, such as upbound vs downbound traffic are essentially correct and can be extended to make estimates for the new locks.

- Locking times are largely a function of ship size (length, beam, draft) relative to lock size. That is, ships are small in terms of the ratio of ship size to lock size have lower locking times than ships that are large relative to lock size. In addition, it is assumed that a small ship has the same locking time in any lock whose size ratio is much larger than the ship size. For example, a Class 7 ship will have the same locking time in either a Class 11 or Class 12 sized lock.

Table 7.8 shows the predicted locking time data for the proposed Class 11 sized locks which could accept a 1100 foot long and 105 foot wide ship. Table 7.9 shows the projected locking times for the Class 12 sized locks that could accept a 1200 foot long and 130 foot wide ships.

7.3.2 Development of Locking Times

Empirical equations, developed from lock records of the St. Lawrence Cote St. Catherine Lock for the SPAN Study [13], were used to obtain estimates for the lock entrance and exit

TABLE 7.6 SOO LOCKS FLEET GROWTH
STRUCTURAL ALTERNTIVE 5 - SOO LOCKS EXPANDED TO ACCEPT
1100 x 105 FOOT SHIPS; WELLAND AND SLR REMAIN UNCHANGED
CARGO CONSTRAINED BY CAPACITY AT THE WELLAND CANAL

CLASS	ORE	COAL	STONE	GRAIN	OTHER BULK	GENERAL CARGO
4	0	0	0	0	30	20
5*	10	10	40	10	60	0
6**	0	5	0	20	0	80
7	20	30	60	70	10	0
8	10	10	0	0	0	0
9	0	0	0	0	0	0
10	10	10	0	0	0	0
11	50	35	0	0	0	0

* Class 5 and 6 lakers
** Ocean class

- Ore - Some Class 5, 6, 8 U.S. ore carriers will continue to be built because of port restrictions; Canadian ore shipments will be made in Class 7 because the dimensions of the Welland Canal remain fixed. U.S. ore shipments will be likely to move to the larger ships since the facilities to handle these ships would be available or quickly developed.

- Coal - Some U.S. coal will continue to move in smaller ships because of port restrictions. Coal for Canadian ports in Lake Ontario and for transshipment overseas will be carried in Class 7's. Coal for ports west of the Welland Canal will be expected to move in larger ships.

- Stone - Demand for stone is not expected to increase to the extent that large ships would be required.

- Grain - A high percentage of grain shipments are in foreign and Canadian ships, therefore growth in ocean Class 6 and Class 7 ships is expected.

- Other Bulk and General Cargo - Growth for these cargos remains the same as for the base line fleet.

TABLE 7.7 WELLAND CANAL AND SLR FLEET GROWTH
STRUCTURAL ALTERNATIVE 5 - SOO LOCKS EXPANDED TO ACCEPT
1100 x 105 FOOT SHIPS; WELLAND CANAL AND SLR REMAIN UNCHANGED

CLASS	ORE	COAL	STONE	GRAIN	OTHER BULK	GENERAL CARGO
4	0	0	0	0	20	20
5*	20	10	20	5	30	0
6**	0	10	10	35	30	80
7	80	80	70	60	20	0

* Class 5 and 6 lakers
** Ocean class

Fleet growth in all categories follows the base line.

TABLE 7.8 LOCKAGE TIME DATA FOR LOCKS CAPABLE OF PROCESSING CLASS 11 SHIPS

SOO LOCKS - Locking Times

4	5	6	7	8	9	10	11	Ship Class	
73.0	75.0	74.0	77.0	78.0	0.0	0.0	0.0	Down	Sabin
68.0	65.0	65.0	61.0	68.0	0.0	0.0	0.0	Up	Sabin
73.0	75.0	74.0	77.0	78.0	101.0	106.0	115.0	Down	MacArthur, Poe, Davis
68.0	65.0	65.0	61.0	68.0	73.0	89.0	98.0	Up	MacArthur, Poe, Davis

WELLAND LOCKS - Locking Times

4	5	6	7	8	9	10	11	Ship Class	
35.0	35.0	43.0	45.0	49.0	61.0	67.0	70.0	Down	Constraining Lock
39.0	39.0	45.0	46.0	50.0	63.0	69.0	72.0	Up	Constraining Lock
34.0	34.0	38.0	40.0	45.0	53.0	57.0	61.0	Down	Non-Constraining Lock
34.0	34.0	38.0	39.0	47.0	55.0	59.0	63.0	Up	Non-Constraining Lock

ST. LAWRENCE RIVER LOCKS - Locking Times

4	5	6	7	8	9	10	11	Ship Class	
34.0	34.0	38.0	40.0	43.0	53.0	57.0	61.0	Down	Constraining Lock
34.0	34.0	39.0	40.0	43.0	53.0	57.0	61.0	Up	Constraining Lock
31.0	31.0	35.0	36.0	39.0	48.0	52.0	56.0	Down	Non-Constraining Lock
31.0	31.0	35.0	36.0	39.0	48.0	52.0	56.0	Up	Non-Constraining Lock

TABLE 7.9 LOCKAGE TIME DATA FOR LOCKS CAPABLE OF PROCESSING CLASS 12 SHIPS

SOO LOCKS - Locking Time

4	5	6	7	8	9	10	11	12	Ship Class	
73.0	75.0	74.0	77.0	78.0	0.0	0.0	0.0	0.0	Down	Sabin
68.0	65.0	65.0	61.0	68.0	0.0	0.0	0.0	0.0	Up	Sabin
73.0	75.0	74.0	77.0	78.0	101.0	106.0	115.0	126.0	Down	MacArthur, Poe, Davis
68.0	65.0	65.0	61.0	68.0	73.0	89.0	98.0	113.0	Up	MacArthur, Poe, Davis

WELLAND LOCKS - Locking Time

4	5	6	7	8	9	10	11	12	Ship Class	
35.0	35.0	43.0	45.0	49.0	55.0	60.0	63.0	75.0	Down	Constraining Lock
39.0	39.0	45.0	46.0	50.0	57.0	62.0	65.0	77.0	Up	Constraining Lock
34.0	34.0	38.0	40.0	45.0	50.0	54.0	58.0	70.0	Down	Non-Constraining Lock
34.0	34.0	38.0	39.0	47.0	52.0	56.0	60.0	72.0	Up	Non-Constraining Lock

ST. LAWRENCE RIVER LOCKS - Locking Times

4	5	6	7	8	9	10	11	12	Ship Class	
34.0	34.0	38.0	40.0	43.0	50.0	54.0	58.0	70.0	Down	Constraining Lock
34.0	34.0	39.0	40.0	43.0	50.0	54.0	58.0	70.0	Up	Constraining Lock
31.0	31.0	35.0	36.0	39.0	45.0	49.0	53.0	65.0	Down	Non-Constraining Lock
31.0	31.0	35.0	36.0	39.0	45.0	49.0	53.0	65.0	Up	Non-Constraining Lock

times. These entry and exit times correspond to the (Σapproach + Σentry) and (Σchamber exit + Σthroat exit) times described earlier in this report in Section 5.3. Times were calculated for vessels of Class 7 through 10 using maximum ship sizes shown below chosen from "Greenwood's Guide to Great Lakes Shipping":

SHIP CLASS	LENGTH x BEAM (ft)
7	730 x 75
8	826 x 75
9	858 x 105
10	1000 x 105

These times were then compared to the corresponding MacArthur-Poe locking times in Section 5.3. The correlation was reasonable in all cases although better correlation was obtained for upbound times than for downbound times. Based on these results, these equations were judged acceptable for use as a first approximation. Table 7.10 shows the equations and the results of the calculations of locking times for the new ship classes. Time in the lock was chosen based on the data presented earlier in Section 5.3.

The results shown in the first two tables of 7.10 were adjusted by preserving the approximate percent differences between the predicted upbound and downbound locking times and the constraining and non-constraining locking times as occur between recorded values of these quantities. Also, as in Section 5.3, the St. Lawrence River constraining locking times were the same as the Welland non-constraining locking times. At the Soo, the Davis Lock is expanded so that it is similar to the current Poe Lock. Therefore, the new Sabin/Davis combination is predicted to have locking times that are approximately the same as the present MacArthur/Poe combination.

The locking times that result from these computations agree with current experience since they show substantial differences in locking times between 75 foot and 105 foot beam ships at the 1100 x 105 foot ship size locks, and also between 105 ft and 130 ft beam ships at the 1200 x 130 foot ship size locks. Also, Class 10 ships have decreased locking times in the new larger locks because they are now smaller relative to the lock size.

TABLE 7.10 DEVELOPMENT OF LOCKING TIMES

EQUATIONS

UPBOUND

$$\bar{t}_{entry} = 1.97 \times 10^{-4} (L \times B) + 6.58$$

$$\bar{t}_{exit} = 1.04 \times 10^{-4} (L \times B) + 5.53$$

DOWNBOUND

$$\bar{t}_{entry} = 2.59 \times 10^{-4} (L \times B) + 4.92$$

$$\bar{t}_{exit} = 1.62 \times 10^{-4} (L \times B) + 4.07$$

NUMBERS

UPBOUND

SHIP CLASS	$\bar{t}_{entry}$	$\bar{t}_{in\ lock}$	$\bar{t}_{exit}$	$\bar{t}_{total}$
8	19	14	12	45
9	24	14	15	53
10	27	14	16	57
11	29	14	18	61
12	37	14	22	73

DOWNBOUND

SHIP CLASS	$\bar{t}_{entry}$	$\bar{t}_{in\ lock}$	$\bar{t}_{exit}$	$\bar{t}_{total}$
8	21	14	14	49
9	28	14	19	61
10	32	14	21	67
11	35	14	23	70
12	45	14	29	88

SOO LOCKS

SHIP CLASS	$\bar{t}_{entry}$		$\bar{t}_{in\ lock}$		$\bar{t}_{exit}$		$\bar{t}_{total}$	
	up	down	up	down	up	down	up	down
12	37	45	54	52	22	29	113	126

7.4 Scenario No. 1 - 1350 by 115 Foot Locks

7.4.1 Scenario Description

After reaching capacity with non-structural alternatives implemented to maximum utility, 1350 by 115 foot locks were placed in operation. These locks are capable of handling ships 1100 by 105 feet, which are considered to be Class 11. No increase in system draft from 25.5 feet was made.

At the Soo Locks, which reached capacity with non-structural alternatives implemented to maximum utility in 2018, a single 1350 by 115 foot lock was constructed. This lock was built in place of the Davis Lock. The existing Sabin, MacArthur, and Poe Locks were not changed. The non-structural improvements were also implemented on this new lock.

At the Welland Canal, which reached capacity with non-structural alternatives implemented to maximum utility in 1996, the existing eight lock system was scrapped and a new lock system consisting of four 1350 by 115 foot locks was built in its place. The non-structural improvements retrofitted on the existing locks were assumed to be built into the new locks.

At the St. Lawrence River, which reached capacity with non-structural alternatives implemented to maximum utility in 2024, the existing seven lock system was scrapped and a new lock system consisting of five 1350 by 115 foot locks was built. In the new St. Lawrence River Lock System the Snell and Eisenhower Locks were combined into a single lock as were the Upper and Lower Beauharnois. The non-structural improvements, retrofitted on the existing locks, were assumed to be built into the new locks.

7.4.2 Results of Capacity Simulation

7.4.2.1 Soo Locks - Construction of a 1350 by 115 foot lock in place of the existing Davis Lock extended capacity at the Soo Locks up to 2050. At capacity in 2050, 272,245,000 short tons of cargo were processed through the Soo Locks. This is an increase of 75,479,000 short tons or 38.4% over the amount of cargo processed through the locks in 2018 when the system was at capacity with the non-structural alternatives combined to maximum utility.

In the period between 2018 and 2050, iron ore and grain had the largest increases in demand through the Soo. Iron ore increased 45.2% and grain increased 29.7%.

The number of ships in the Soo Locks fleet did not increase significantly between 2018 and 2050, increasing 0.8% from 169.3 ships in 2018 to 170.6 ships in 2050. The increase in composite ship class from 7.1 in 2018 to 8.1 in 2050 was much more significant. Because of the new, larger lock, the percentages of Class 10 and 11 ships increased from 19.5% of the Soo fleet in 2018 to 50.4% of the fleet in 2050. Since larger ships carry more tonnage per minute of locking time than smaller ships, this yielded large increases in capacity. The Soo fleet mix is shown on Figure 7.1.

The number of actual transits through the Soo Locks decreased 3.6%, from 11,807 transits in 2018 to 11,379 transits in 2050. The number of transits decreased because larger ships require more time to lock than do smaller ships. The ratio of loaded transits to total transits increased from 56.1% in 2018 to 58.7% in 2050. This is due to a more even balance between upbound and downbound commodities. Capacity increased due to a reduction in ballasted transits.

Capacity was reached by both the Poe and the new Davis Locks in 2050. The Poe had an average lock utilization during the peak months of May to November of 90.6%. The most severe congestion occurred at the Poe in June when lock utilization was 92%, average vessel waiting time was 4.9 hours upbound and 15.1 hours downbound, and average queue length was 1.6 vessels upbound and 5.2 vessels downbound. The new Davis Lock had an average lock utilization of 90.9% during the peak months of May through November. During the most congested month, May, lock utilization was 92%, average vessel waiting time was 5.2 hours upbound and 16.3 hours downbound, and average queue length was 1.6 vessels upbound and 5.4 vessels downbound. Lock utilization, vessel waiting time, and queue length are given in Figure 7.2 for the Poe Lock and Figure 7.3 for the new Davis Lock.

Both the Sabin and MacArthur Locks were under-utilized with average utilization of 25.0% at the Sabin and 38.0% at the MacArthur. Utilization for these locks decreased from 2018 to 2050 as the percentage of ships that could use these locks decreased. Lock utilization, average vessel waiting time, and average queue length for the MacArthur Lock are given on Figure 7.4.

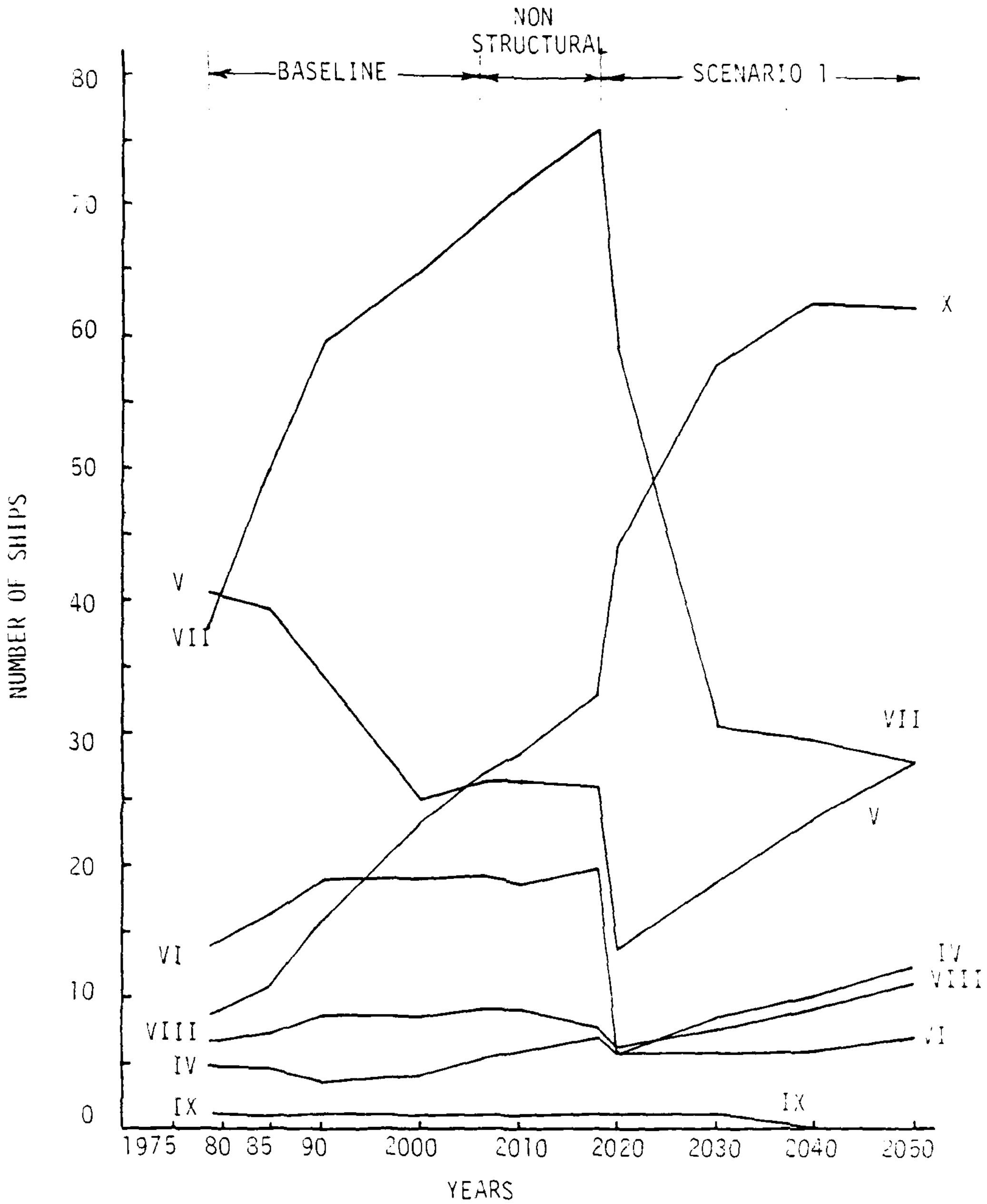

FIGURE 7.1 FLEET MIX, SOO LOCKS - SCENARIO 1 PLUS BASELINE AND NON-STRUCTURAL ALTERNATIVES TO MAXIMUM UTILITY

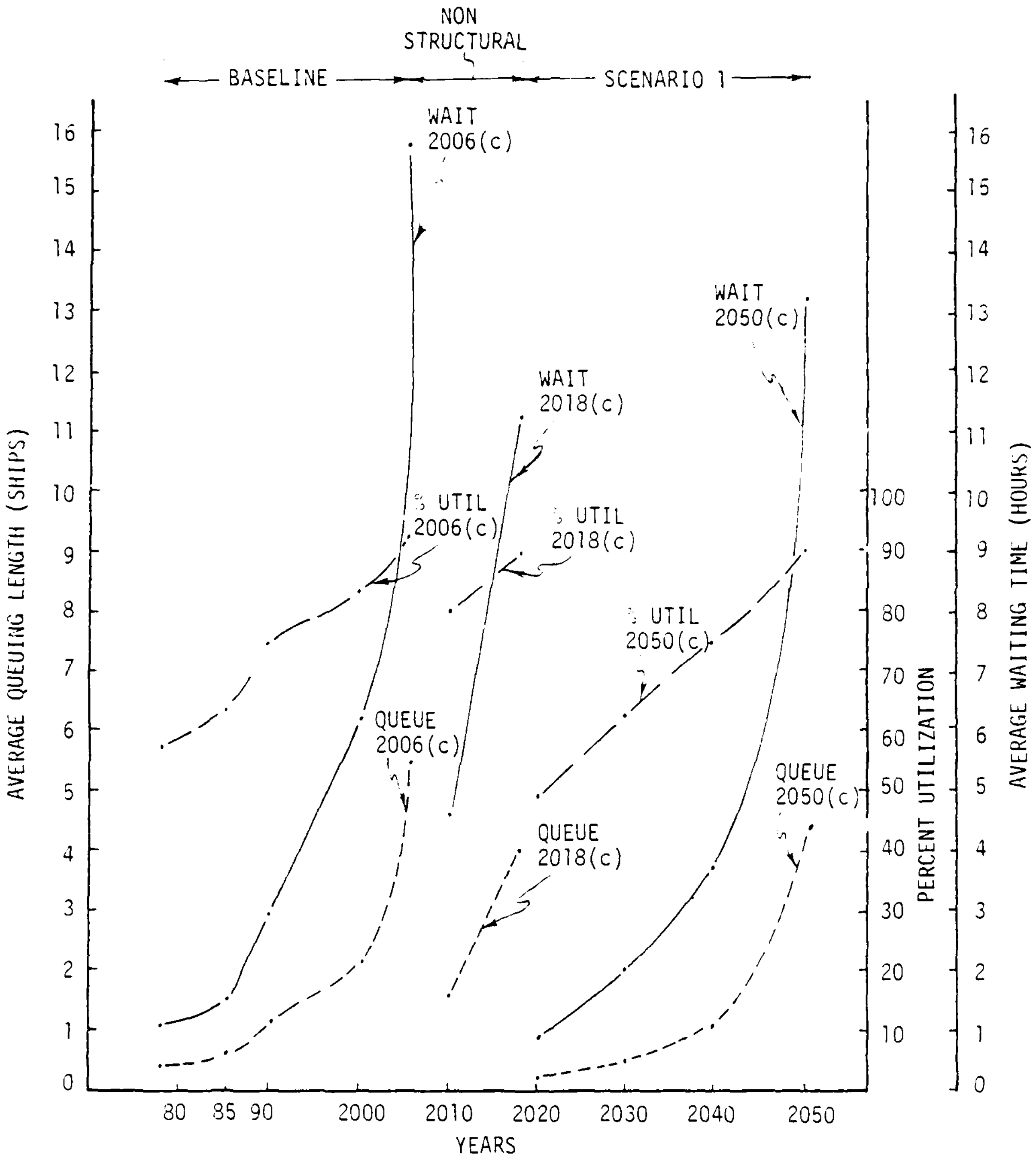

FIGURE 7.2 SCENARIO 1, POE LOCK - QUEUE LENGTH, WAITING TIME, % UTILIZATION

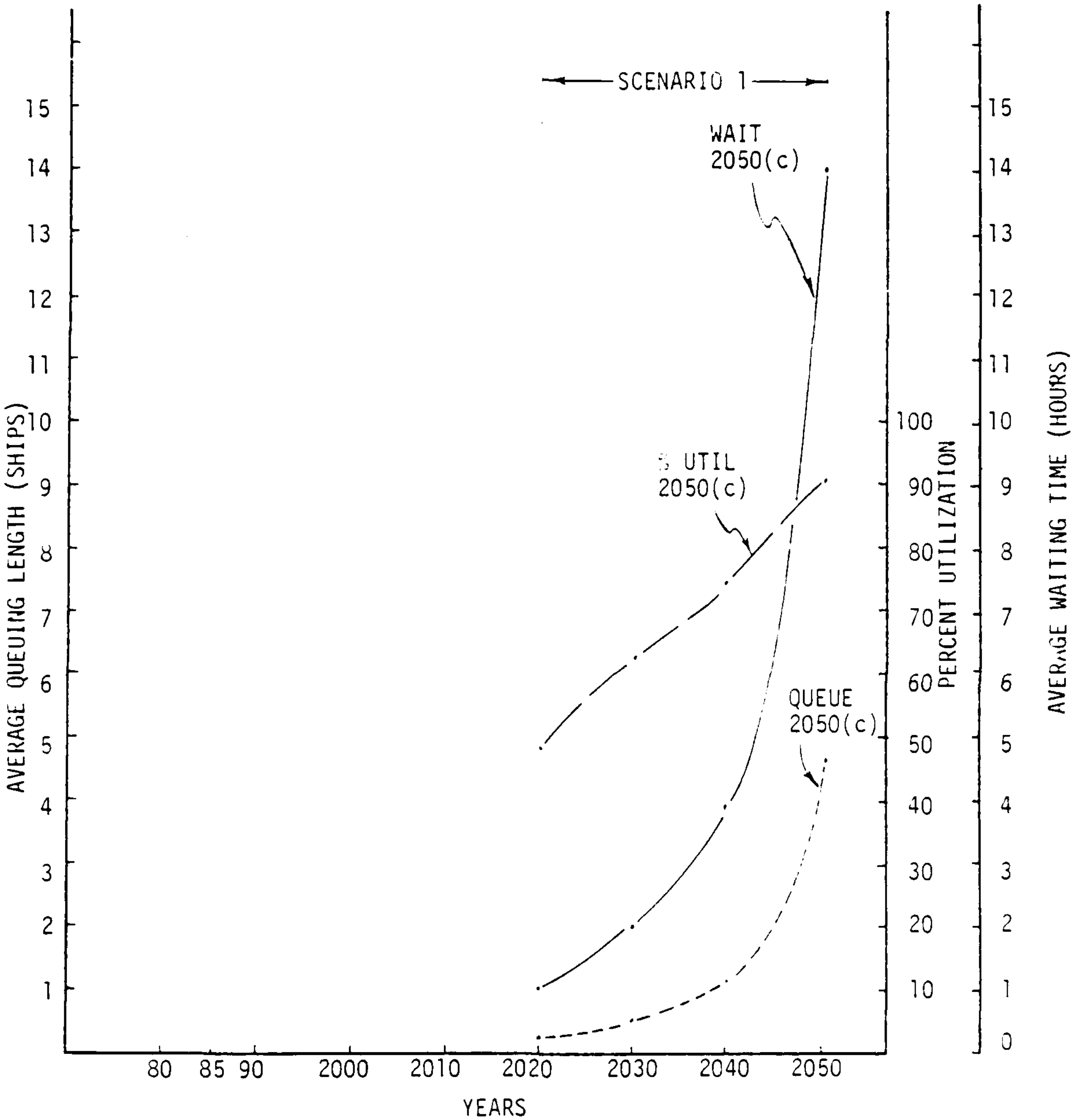

FIGURE 7.3 SCENARIO 1, NEW DAVIS LOCK - QUEUE LENGTH, WAITING TIME, % UTILIZATION

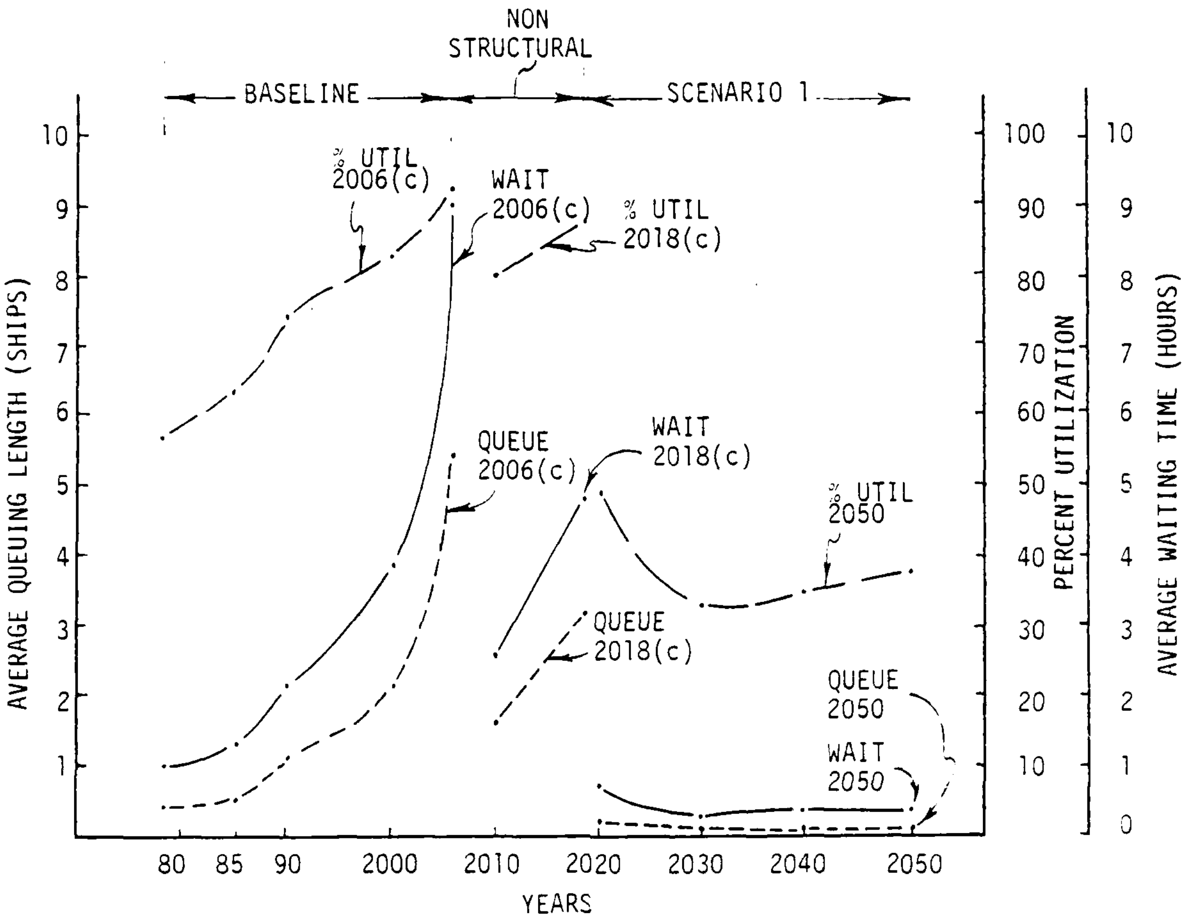

FIGURE 7.4 SCENARIO 1, MACARTHUR LOCK - QUEUE LENGTH, WAITING TIME, % UTILIZATION

7.4.2.2 Welland Canal - Construction of a new Welland Canal consisting of four 1350 x 115 foot locks extended capacity through that section of the GL/SLS System to 2034. At capacity in 2034, 128,693,000 short tons of cargo passed through the new Welland Canal. This tonnage is an increase of 40,095,000 short tons or 45.3% over the capacity tonnage of 88,598,000 short tons processed through the existing Welland Canal in 1996 when capacity was reached with non-structural alternatives implemented to maximum utility.

By commodity, the largest cargo demand increases were in general cargo, other bulk, and iron ore. General cargo increased 74.7%, other bulk increased 66.9%, and iron ore increased 52.9%. Although it increased at a much slower rate, grain also showed a significant gain of 32.4% during the period.

There was almost no change in the number of ships in the Welland Canal fleet between 1996 and 2034, with 147.0 ships in 1996 and 146.9 ships in 2034. The 45.3% increase in tonnage through the Welland was mainly the result of an increase in the composite ship size from 6.2 in 1996 to 7.2 in 2034. The increased ship size meant more tons of cargo per lock operating minute, causing a significant capacity increase. The Welland Canal fleet mix is shown on Figure 7.5.

The total number of transits through the Welland Canal decreased 8.6% from 8,075 transits in 1996 to 7,380 transits in 2034. This would be expected since larger ships take more time to lock than smaller ships. The larger ships carry more tonnage however, more than making up for the decreased number of transits. Due to a better balance between upbound and downbound cargo flows in 2034, the ratio of loaded transits to total transits increased from 63.9% in 1996 to 65.2% in 2034. This resulted in a small capacity increase due to increased ship utilization and reduced empty backhauls.

At capacity in 2034, the average lock utilization for the constraining lock on the new Welland Canal Canal was 92.1 for May through November. During the most congested month, July, lock utilization was 97.0%, average vessel waiting time was 25.1 hours upbound and 11.5 hours downbound, and average queue length was 17.4 ships upbound and 3.0 ships downbound. Lock utilization, average vessel waiting time, and average queue length are shown on Figure 7.6.

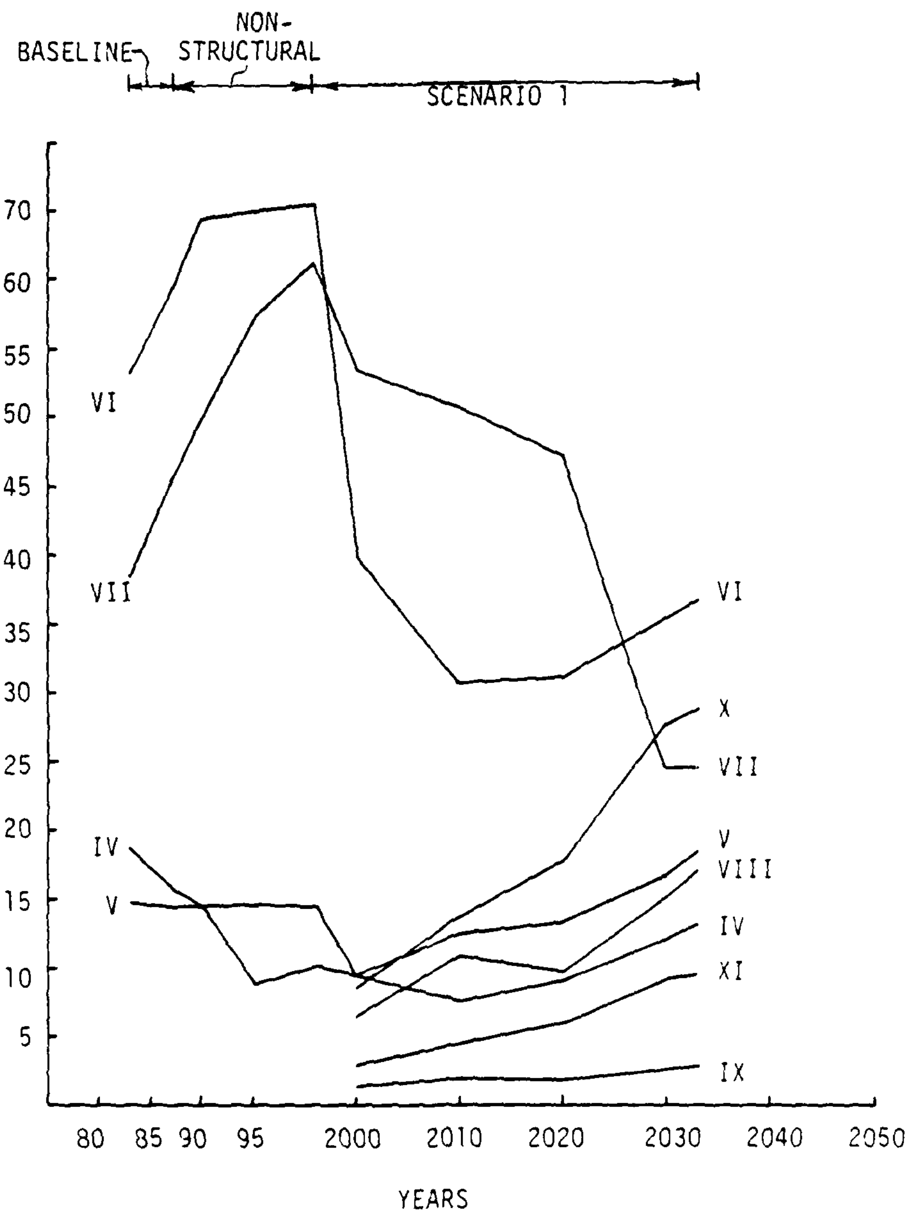

FIGURE 7.5 FLEET MIX, WELLAND CANAL - SCENARIO 1 PLUS BASELINE AND NON-STRUCTURAL ALTERNATIVE TO MAXIMUM UTILITY

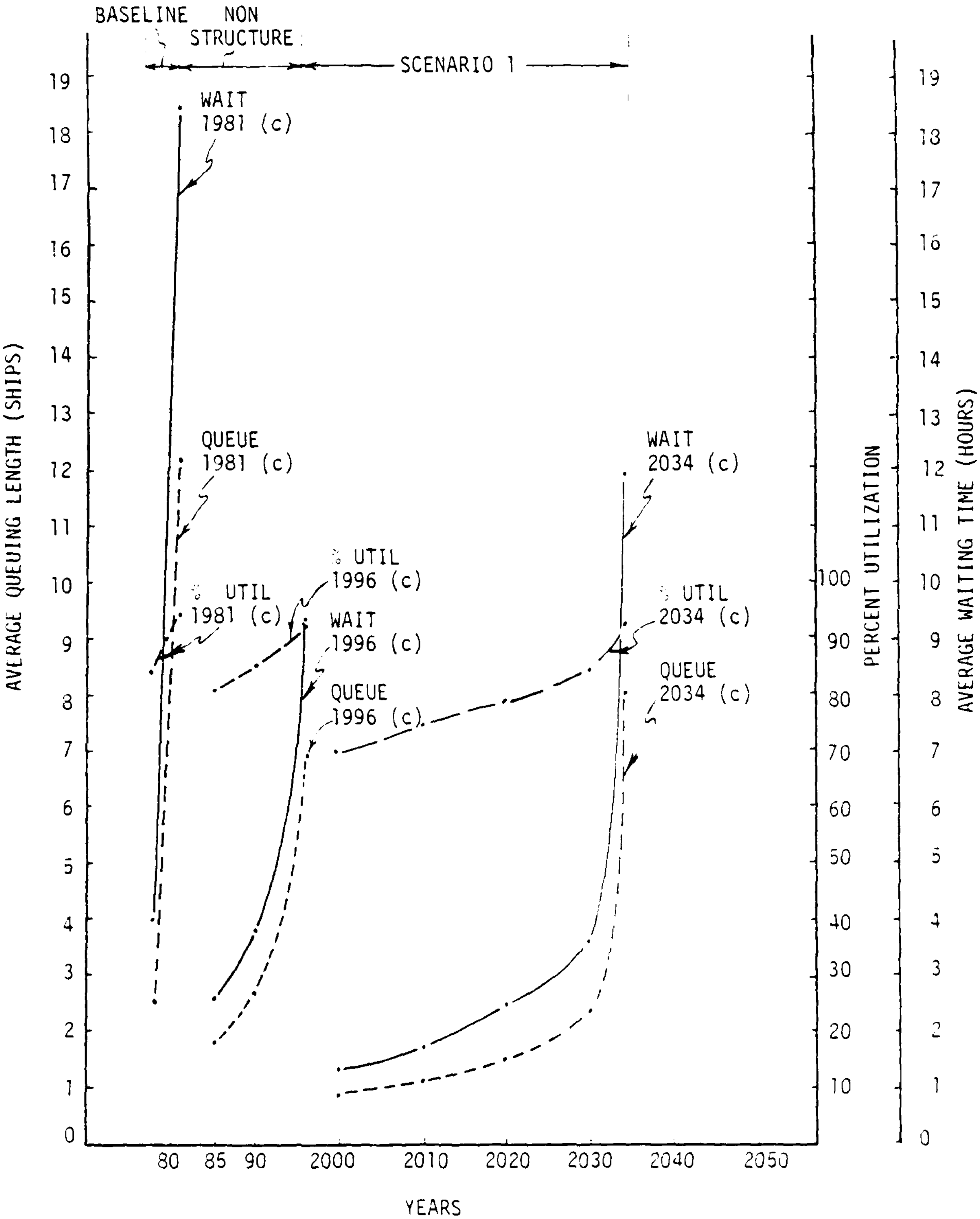

FIGURE 7.6 SCENARIO 1, WELLAND CANAL - QUEUE LENGTH, WAITING TIME, UTILIZATION

7.4.2.3 St. Lawrence River - Construction of a series of five 1350 by 115 foot locks in the St. Lawerence River to replace the existing seven St. Lawrence River Locks postponed capacity at that segment of the GL/SLS System until 2048. At capacity in 2048 a total of 144,539,000 short tons of cargo were passed through the new St. Lawrence River Locks. This total is an increase of 35,942,000 short tons or 33.1% over the 108,597,000 short tons passed through the existing St. Lawrence River Lock System in 2024 when capacity was reached with non-structural alternatives combined to maximum utility.

The commodities that increased most significantly between 2024 and 2048 were general cargo and other bulk. General cargo increased 77.9% and other bulk increased 38.2%. Also increasing significantly, but not at such high rates, were grain at 20.9% and iron ore at 25.4%.

From 2024 to 2048 the St. Lawrence River fleet increased only slightly from 179.2 ships to 182.3 ships. More important, the composite ship class in the fleet increased from 6.1 in 2024 to 7.1 in 2048. Larger ships increase system capacity because the increase in the carrying capacity of the ship more than offsets the increased lockage time. The St. Lawrence River fleet mix is shown on Figure 7.7.

As was expected, since larger ships take more time to lock, the total number of transits through the St. Lawrence River decreased 8.5% from 9,345 transits in 2024 to 8,553 transits in 2048. The ratio of loaded transits to total transits remained constant at 70.0% from 2024 to 2048. No capacity increase was gained due to reduced percentage of empty backhauls.

At capacity in 2048, lock utilization of the constraining lock on the new St. Lawrence River System was 93.0% for the peak months of May through November. During the most congested month, July, lock utilization was greater than 98.0%, average vessel waiting time was 30.2 hours upbound and 30.4 hours downbound, and average queue length was 24.6 vessels both upbound and downbound. Lock utilization, average vessel waiting time, and average queue length are given on Figure 7.8.

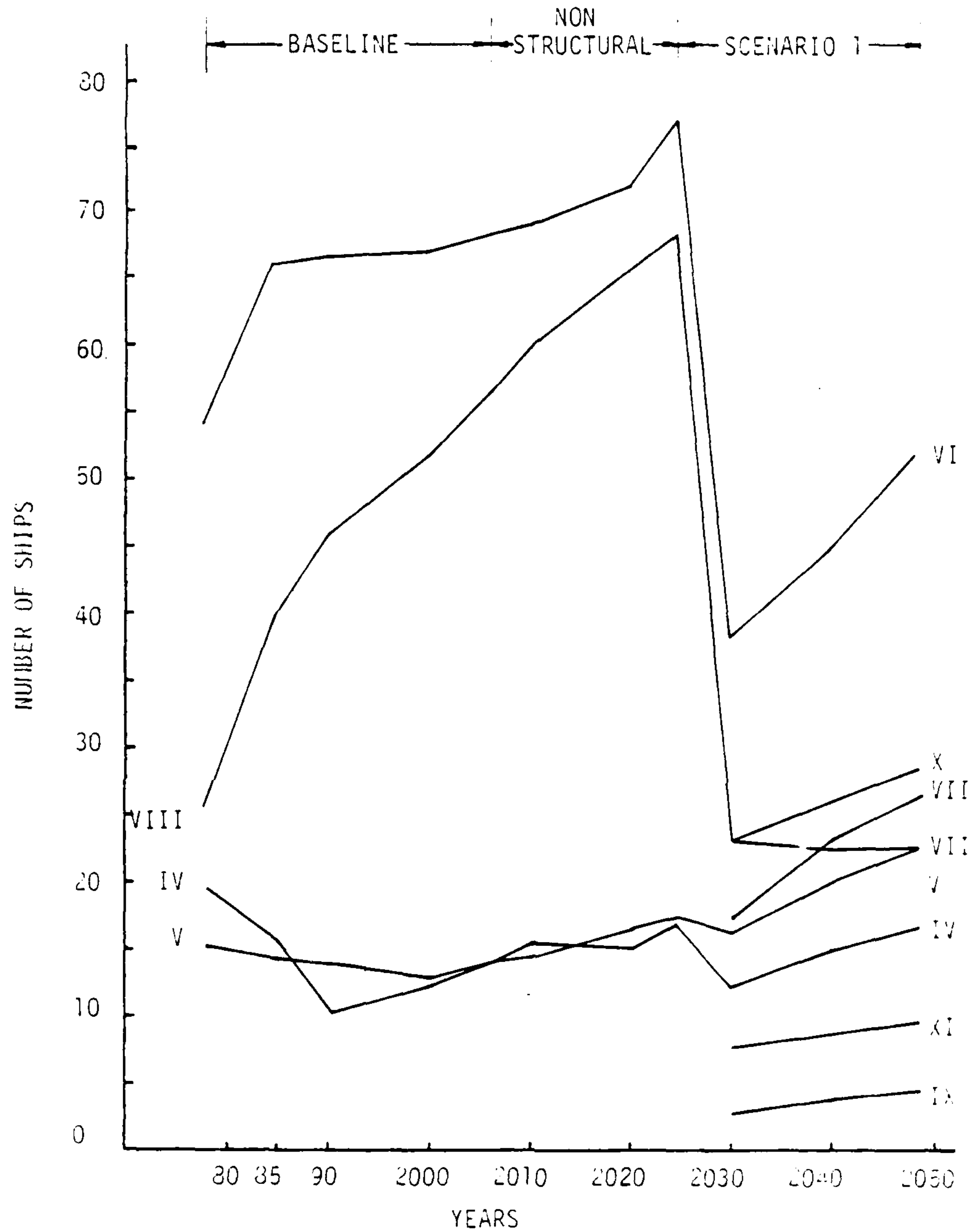

FIGURE 7.7 FLEET MIX, ST. LAWRENCE RIVER - SCENARIO 1, PLUS BASELINE AND NON-STRUCTURAL TO MAXIMUM UTILITY

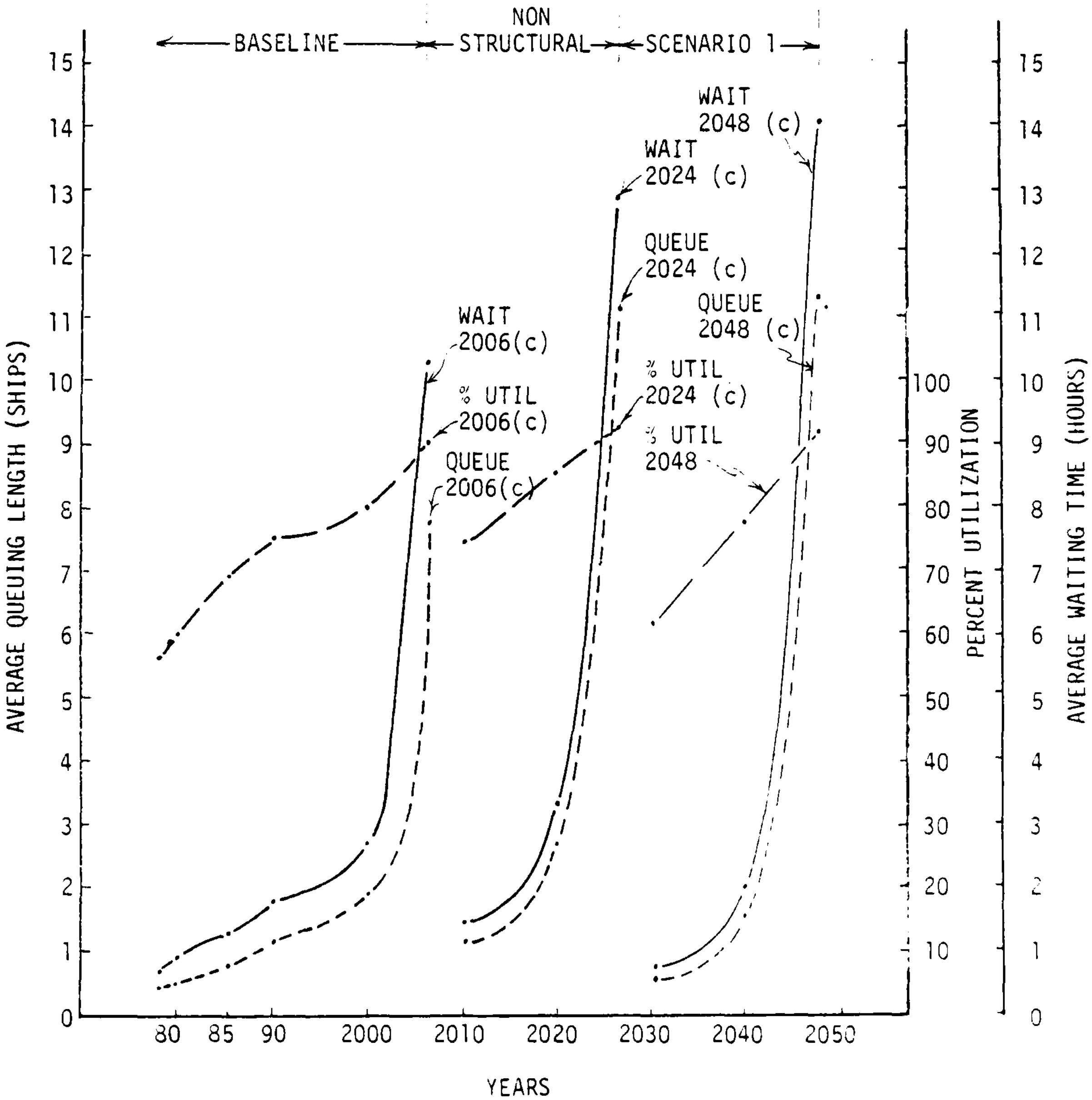

FIGURE 7.8 SCENARIO 1, ST. LAWRENCE RIVER - QUEUE LENGTH, WAITING TIME, % UTILIZATION

7.5 Scenario No. 2 - 1460 by 145 Foot Locks

7.5.1 Scenario Description

New locks were placed in operation at each lock system after capacity was reached with non-structural alternatives implemented to maximum utility. In this case the new locks were 1460 by 145 feet, capable of handling 1200 by 130 foot ships (Class 12). No change in the system draft from 25.5 feet was made.

At the Soo Locks, which reached capacity in 2018 with non-structural alternatives combined to maximum utility, one new 1460 by 145 foot lock was constructed. This new lock was constructed in place of the Sabin and Davis Locks. The Soo Lock System then consisted of the MacArthur and Poe Locks, which were not changed, and the new Sabin-Davis Lock. The non-structural alternatives already in use at the MacArthur and Poe Locks were implemented at the new Sabin-Davis.

At the Welland Canal, which reached capacity in 1996 with non-structural alternatives combined to maximum utility, four new 1460 by 145 foot locks were constructed. These new locks replaced the existing eight locks which were scrapped. The non-structural alternatives that were in use on the existing Welland Canal Locks were assumed to be built into the new locks.

At the St. Lawrence River, which reached capacity in 2024 with non-structural alternatives combined to maximum utility, the existing new locks were scrapped, and a new series of five 1460 by 145 foot locks was built. Construction of the new lock system was optimized by combining the Snell and Eisenhower Locks into one lock, and the Upper and Lower Beauharnois Locks into one lock. The non-structural improvements were built into the five new locks.

7.5.2 Results of Capacity Analysis

7.5.2.1 Soo Locks - Construction of a new 1460 by 145 foot lock to replace the Sabin and Davis Locks allowed the Soo Lock System to pass the 2050 unconstrained cargo forecasts without a capacity situation occurring. The 2050 unconstrained cargo forecast is 272,247,000 short tons. This is an increase

of 75,481,000 short tons or 38.4% over the 196,776,000 short tons of cargo that passed through the Soo Locks at capacity with non-structural alternatives implemented to maximum utility in 2018.

For the period from 2018 to 2050, the commodities that had the largest increases in demand at the Soo were iron ore and grain. Iron ore increased 45.2% and grain increased 29.7%.

Average lock utilization in 2050 for the new Sabin-Davis Lock was 87.0% for the peak months of May through November. This indicates that if the cargo forecasts could be projected to increase in the same patterns as existed before 2050, capacity would be expected at the Soo within the decade after 2050.

It is significant that the new Sabin-Davis Lock becomes the constraining lock at the Soo. This is because a large number of Class 11 and Class 12 ships were added to the Soo fleet between 2018 and 2050. A total of 36.3 ships out of 149.8 ships, or 25.2% of the Soo fleet in 2050, were Class 11 and 12 ships, and these ships could only be served by the new Sabin-Davis Lock.

The Poe Lock had an average lock utilization of 86.7% in 2050, only slightly less than the new Sabin-Davis Lock. The Poe Lock handled Class 8, 9, and 10 ships, which totaled 68.2 ships, or 45.5% of the Soo fleet.

The MacArthur Lock in 2050 had an average lock utilization of only 41.0%. The utilization at this lock decreased as the size of vessels in the Soo fleet increased beyond the size that the MacArthur Lock could handle. Soo Lock capacity could be maximized to a point well beyond 2050, if needed, by also replacing the MacArthur Lock with a lock capable of handling Class 10 or larger sized ships.

The composite vessel class for the Soo Lock fleet in 2050 was 8.5, indicating the great number of very large ships. There were 9,834 transits through the Soo in 2050. These numbers cannot be compared to the 2018 values because a capacity condition did not exist in 2050 and therefore the number of transits will increase over the 2050 total before capacity occurs. The Soo fleet mix is shown on Figure 7.9.

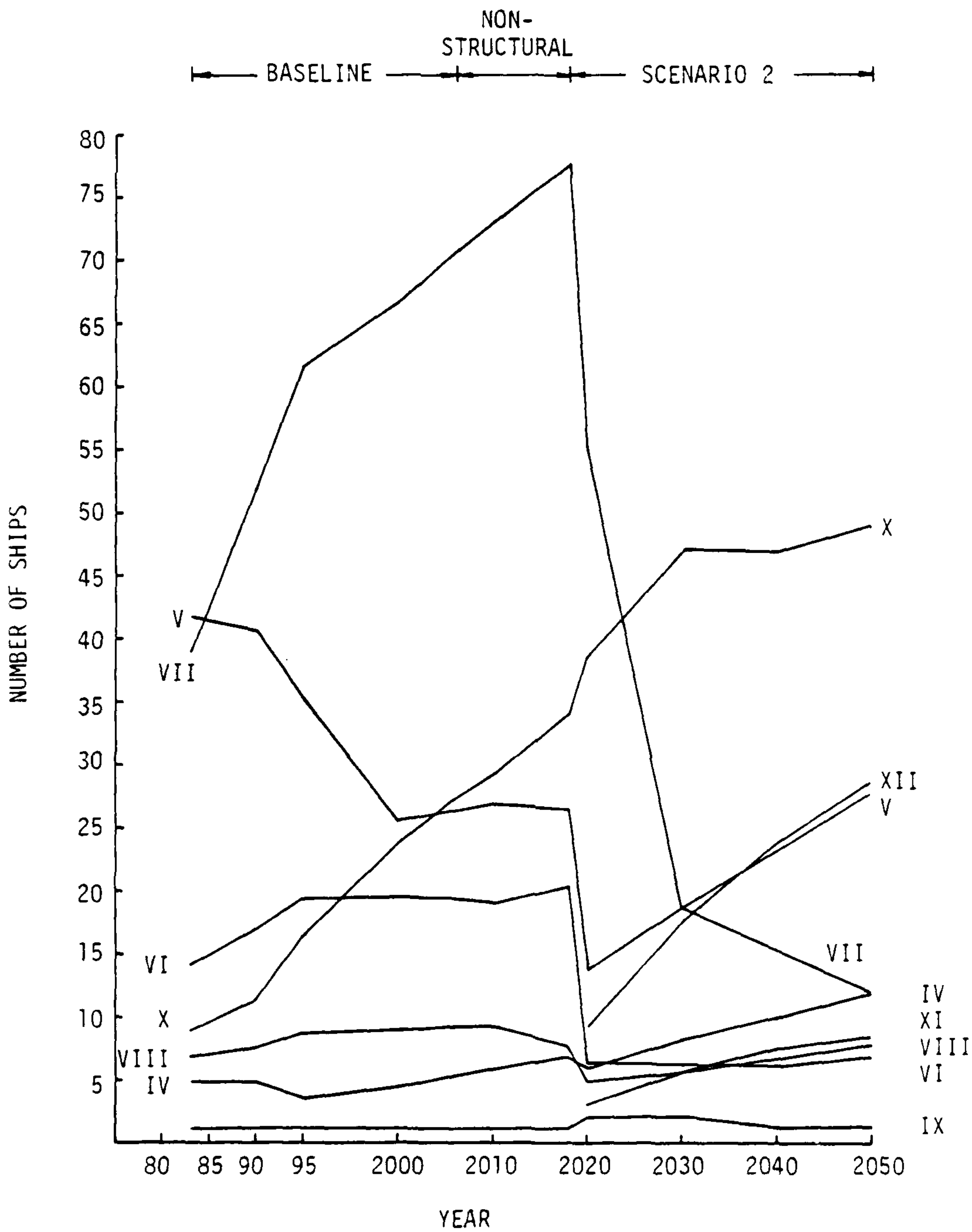

FIGURE 7.9 FLEET MIX, SOO LOCKS - SCENARIO 2 PLUS BASELINE AND NON-STRUCTURAL ALTERNATIVE TO MAXIMUM UTILITY

During June, the most congested month at the new Sabin-Davis Lock, the lock utilization was 88%, average vessel waiting time was 7.1 hours upbound and 11.4 hours downbound, and average queue length was 2.0 ships upbound and 3.2 ships downbound. Lock utilization, average vessel waiting time, and average queue length are given on Figure 7.10. The conditions of the Poe and MacArthur Locks are shown on Figures 7.11 and 7.12, respectively.

7.5.2.2 Welland Canal - With a series of four 1460 by 145 foot locks, the Welland Canal reached capacity in 2046 with a total cargo flow of 148,229,000 short tons. Capacity of the Welland Canal increased by 59,631,000 short tons or 63.9% over the 88,598,000 short tons passed through the locks at capacity in 1996 with non-structural alternatives combined to maximum utility.

The largest increases in commodity flow through the Welland Canal between 1996 and 2046 were in general cargo, other bulk, and iron ore. General cargo increased 125%, other bulk increased 106%, and iron ore increased 73.1%. Grain flows also increased significantly, rising 45.6% in the time period.

The number of ships in the Welland Canal fleet increased 9.4%, from 147.0 ships in 1996 to 160.8 ships in 2046. Most important, however, is the increase in composite ship class from 6.2 in 1996 to 7.8 in 2046. The large increase in fleet size is the main reason for the 59,631,000 short ton capacity increase between 1996 and 2046. The Welland Canal fleet mix is shown on Figure 7.13.

The total number of transits through the Welland Canal decreased 9.1% from 8075 transits in 1996 to 7344 transits in 2046. The reduction in transits occurred because large ships require more time to lock than small ships. The ratio of total transits to loaded transits increased from 63.9% in 1996 to 68.8% in 2046, causing a significant capacity increase due to a reduction in ballasted transits. This reduction occurred as the result of a better balance between upbound and downbound cargo flows.

At capacity in 2046 the constraining lock on the Welland Canal had an average lock utilization of 93.7% during the peak months of May through November. During the most congested month, July, lock utilization was greater than 98.0%, average vessel waiting time was 36.1 hours upbound and 19.2 hours downbound, and average queue length was 24.6 vessels upbound and 13.2 vessels downbound. Lock utilization, average vessel waiting time, and average queue length are shown on Figure 7.14.

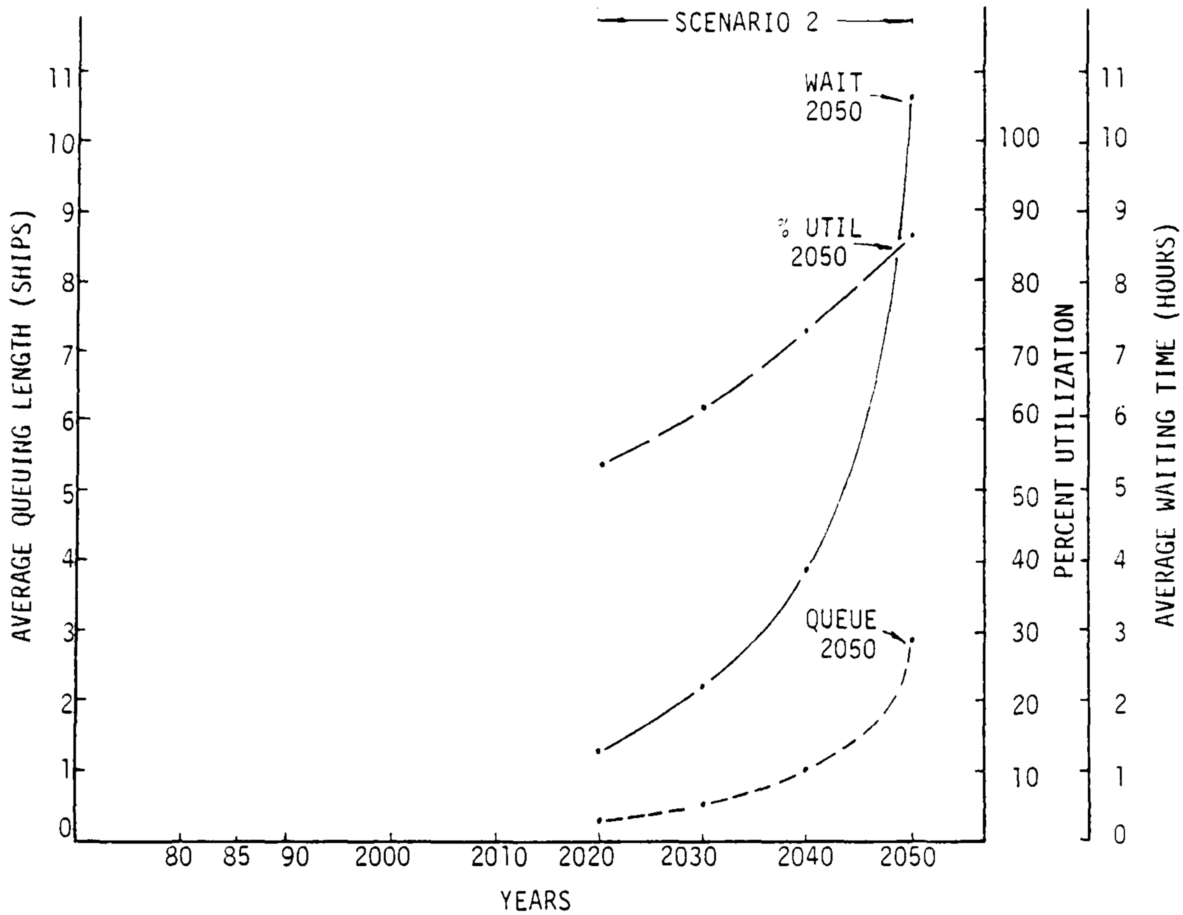

FIGURE 7.10 SCENARIO 2, NEW DAVIS LOCK - QUEUE LENGTH, WAITING TIME, % UTILIZATION

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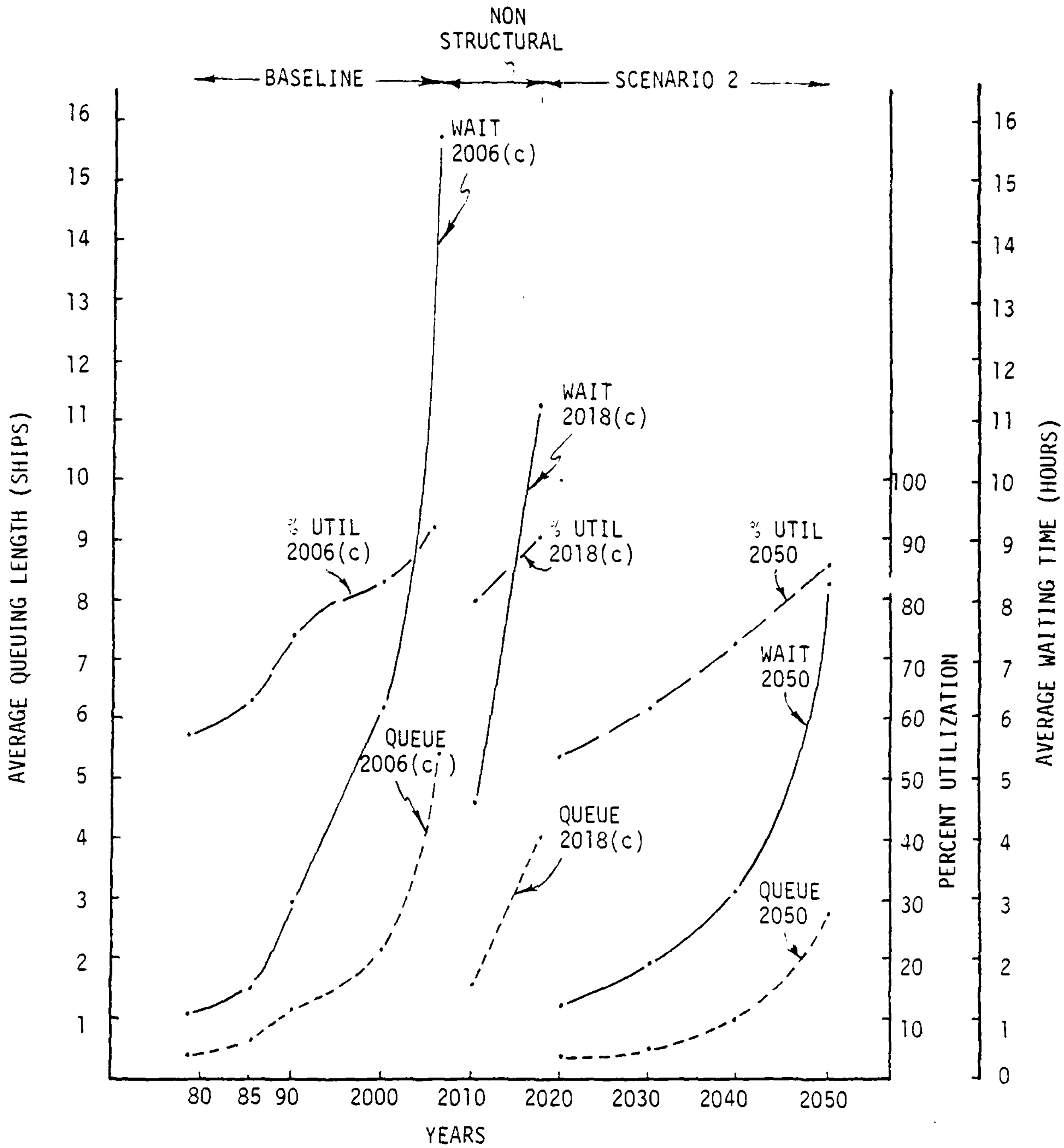

FIGURE 7.11 SCENARIO 2, POE LOCK - QUEUE LENGTH,
WAITING TIME, % UTILIZATION

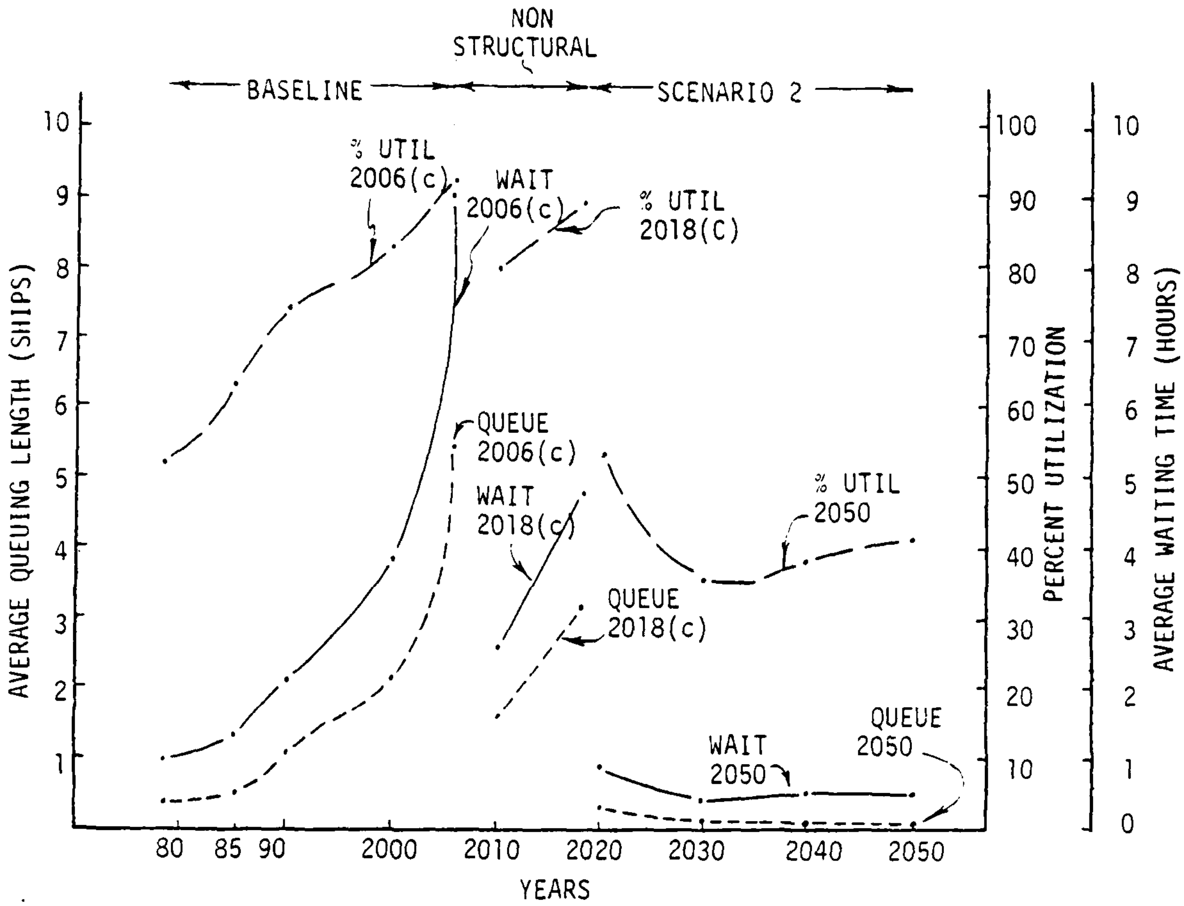

FIGURE 7.12 SCENARIO 2, MACARTHUR LOCK - QUEUE LENGTH, WAITING TIME, % UTILIZATION

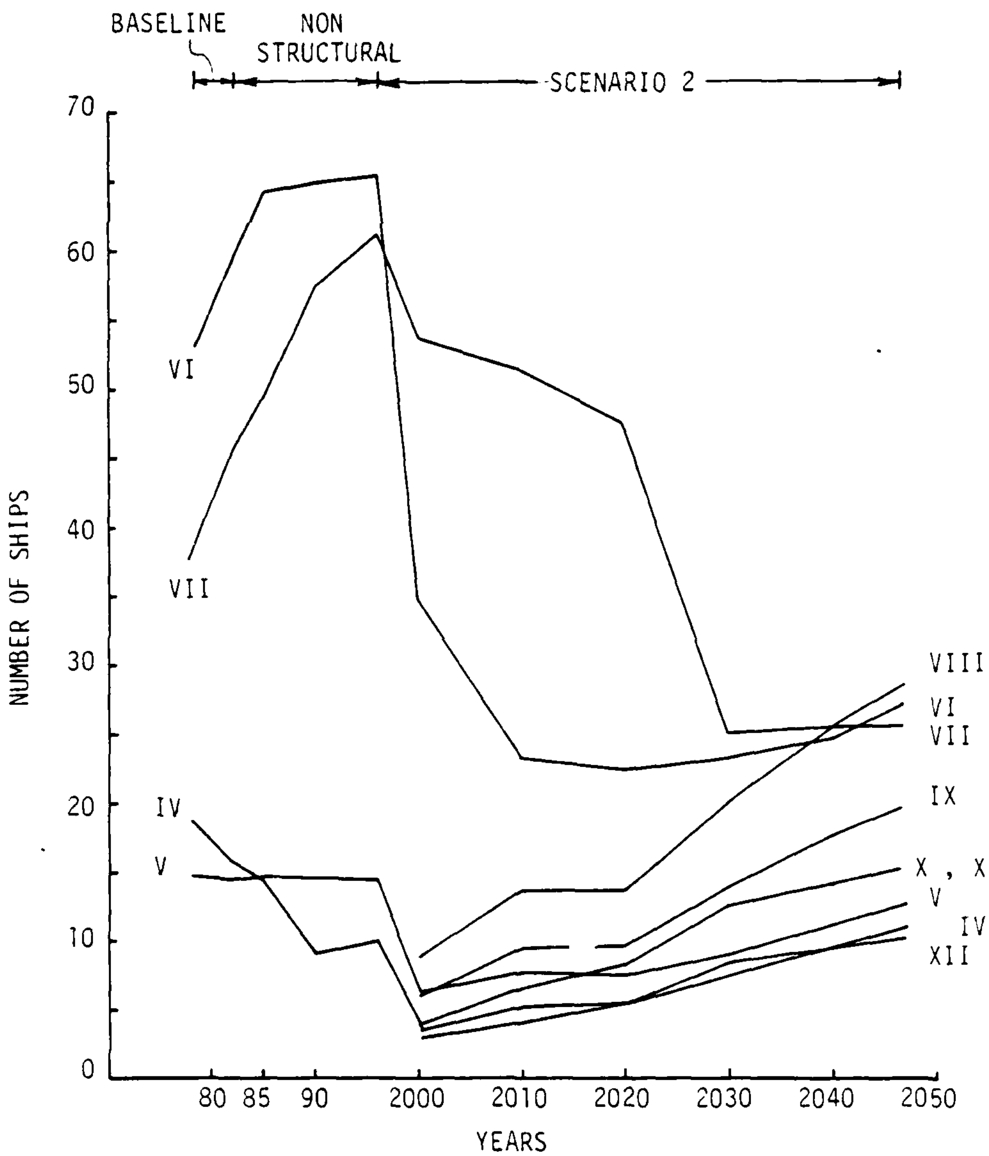

FIGURE 7.13 FLEET MIX, WELLAND CANAL - SCENARIO 2 PLUS BASELINE AND NON-STRUCTURAL ALTERNATIVES TO MAXIMUM UTILITY

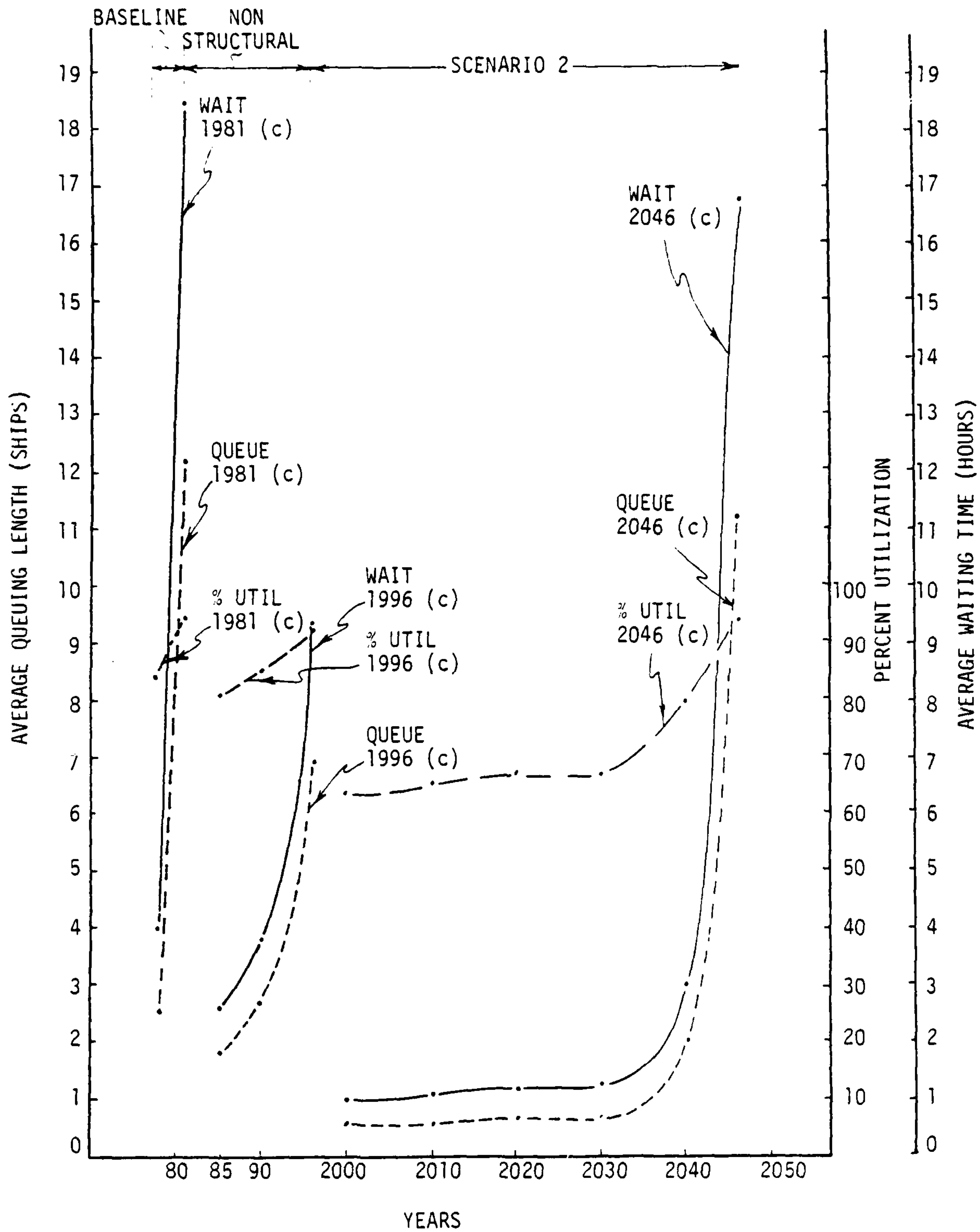

FIGURE 7.14 SCENARIO 2, WELLAND CANAL - QUEUE LENGTH, WAITING TIME, % UTILIZATION

7.5.2.3 St. Lawrence River - By replacing the existing seven St. Lawrence River Locks with five 1460 by 145 foot locks, the 2050 unconstrained cargo forecast may be passed without a capacity condition occurring. The 2050 unconstrained cargo forecast is 148,259,000 short tons. This is an increase of 36.5% or 39,662,000 short tons over the 108,597,000 short tons of cargo passed through the St. Lawrence River when it was at capacity in 2024 with non-structural alternatives combined to maximum utility.

Much of the increased cargo flow through the St. Lawrence River between 2024 and 2050 came from general cargo, other bulk, iron ore, and grain. General cargo increased 85.0%, other bulk increased 42.0%, iron ore increased 28.0%, and grain increased 23.4%.

The total number of vessels in the St. Lawrence River fleet in 2050 was 172.6 ships. The total number of transits through the new St. Lawrence River Locks was 7,454 transits in 2050. Since the system was not at capacity in 2050, these quantities may increase before capacity is reached at some time beyond 2050.

The composite ship class for the St. Lawrence River fleet was 7.7 in 2050. There were 35.7 ships of Class 10 or larger, which are 20.7% of the total fleet. Capacity at the St. Lawrence River will be reached beyond 2050 because of this large increase in ship size. The St. Lawrence River fleet mix is shown on Figure 7.15.

Lock utilization at the constraining lock on the new St. Lawrence River Lock System in 2050 was an average of 78.3% over the peak months of May through November. During the most congested month, July, lock utilization was 84.0%, average vessel waiting time was 3.1 hours upbound and 2.0 hours downbound, and average queue length was 2.3 vessels upbound and 2.2 vessels downbound. Lock utilization, average vessel waiting time, and average queue length are shown on Figure 7.16.

7.6 Scenario No. 3 - 28 Foot Ship Draft

7.6.1 Scenario Description

At each lock system capacity was increased by increasing the allowable ship draft to 28 feet after capacity was reached with non-structural alternatives combined to maximum utility.

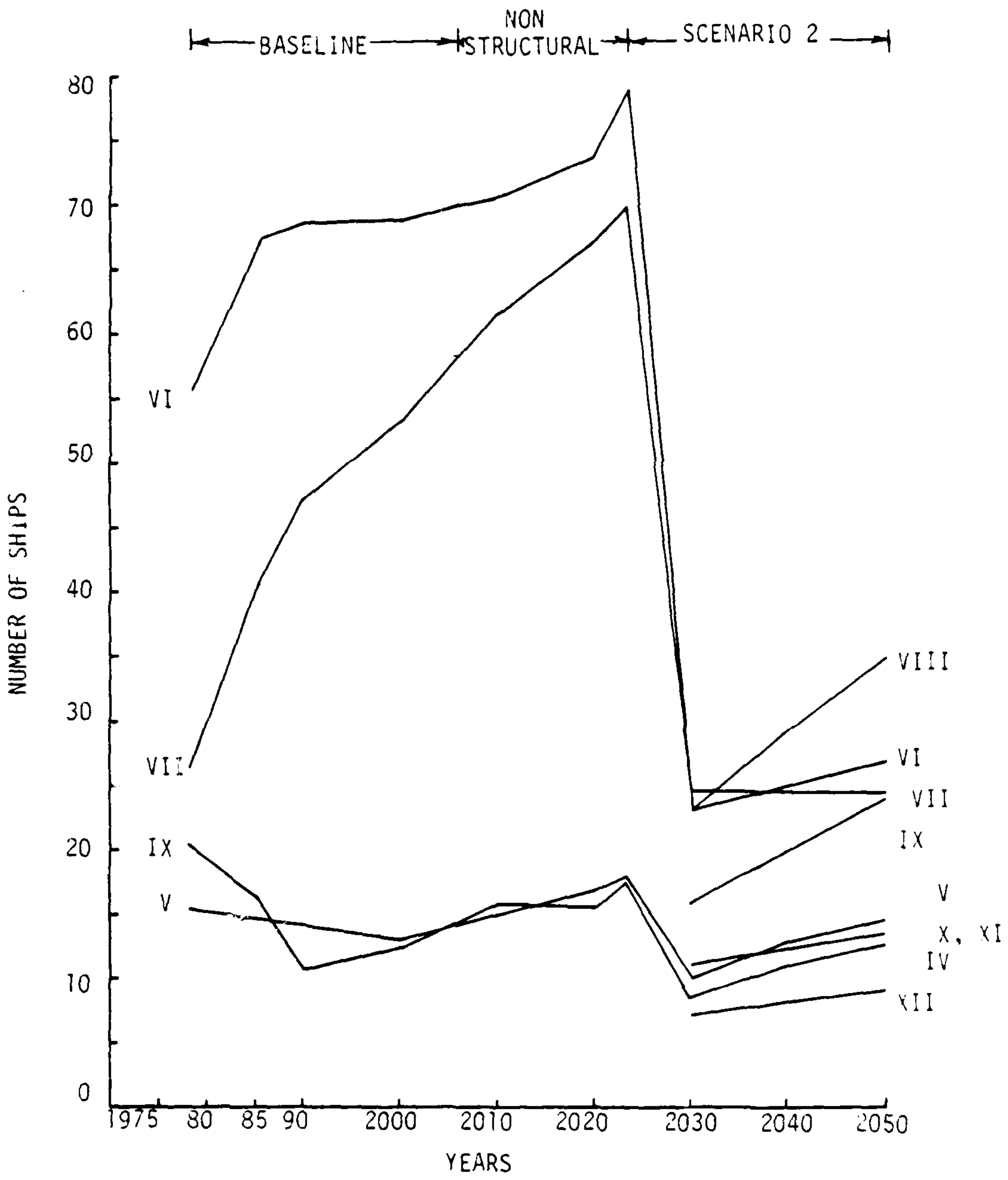

FIGURE 7.15 FLEET MIX, ST. LAWRENCE RIVER - SCENARIO 2 PLUS BASELINE AND NON-STRUCTURAL TO MAXIMUM UTILITY

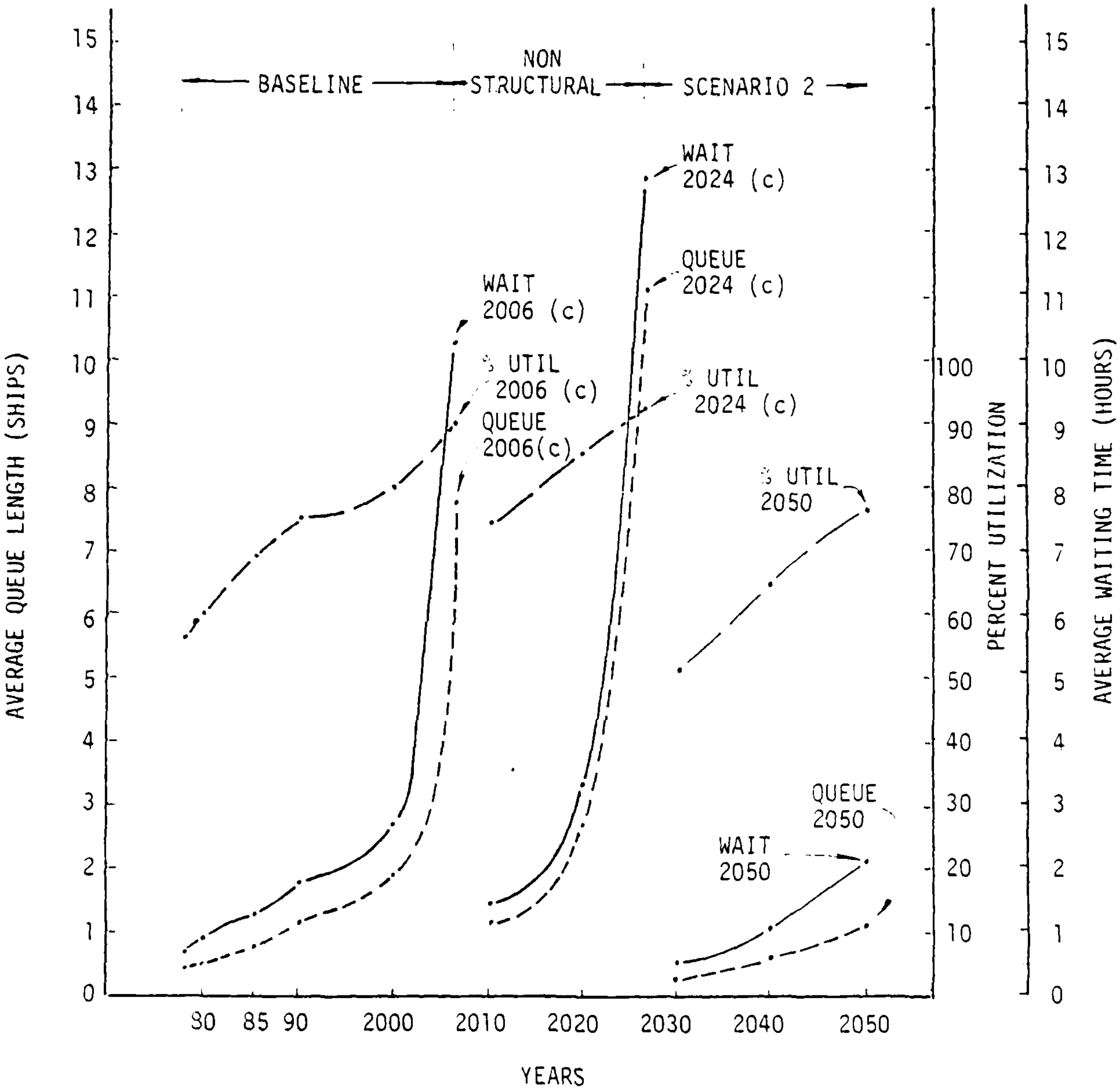

FIGURE 7.16 SCENARIO 2, ST. LAWRENCE RIVER QUEUE LENGTH, WAITING TIME, UTILIZATION

Drafts were not increased at the Sabin and Davis Locks. No other change was made to the size of the locks. The maximum size ships were Class 10 at the Soo and Class 7 at the Welland and St. Lawrence River.

Increasing ship draft increases the capacity of a lock system by increasing the cargo carrying capacity of each ship. This is provided that each ship has a sufficient molded depth to allow it to operate at the increased draft. In the Lock Capacity Model, carrying capacities of the ships were increased by the values found in a capacity increase per inch of immersion table [3]. The capacity increase per inch of immersion for the ships used in this study is given in Table 5.1. Lake ships less than 600 feet long on the GL/SLS System operate at their maximum depth in most cases, therefore in this analysis the capacity of Class 4 ships was not increased beyond the 25.5 foot draft capacity.

7.6.2 Results of Capacity Analysis

7.6.2.1 Soo Locks - With ship draft increased to 28 feet, capacity at the Soo was reached in 2026. The cargo tonnage at capacity in 2026 was 213,734,000 short tons. The 2026 capacity tonnage increased 16,968,000 short tons or 8.6% over the capacity tonnage of 196,766,000 short tons with non-structural alternatives combined to maximum utility in 2018.

The majority of the cargo increase between 2018 and 2026 was in iron ore and grain. Iron ore increased 10.5% and grain increased 6.7%.

The number of vessels in the Soo Locks fleet decreased 3.0%, from 169.3 ships in 2018 to 164.3 ships in 2026. The composite ship class in the Soo fleet remained constant at 7.1. This indicates that the additional capacity at the Soo was due to the increased draft, which also compensated for the capacity of the five ships that were dropped from the fleet. The Soo fleet mix is shown in Figure 7.17.

The total number of transits through the Soo Locks decreased 5.6% from 11,807 transits in 2018 to 11,147 transits in 2026. The ratio of loaded transits to total transits remained constant at 56.1%.

At capacity in 2026 the Poe Lock had an average lock utilization of 92.0% over the peak months of May through

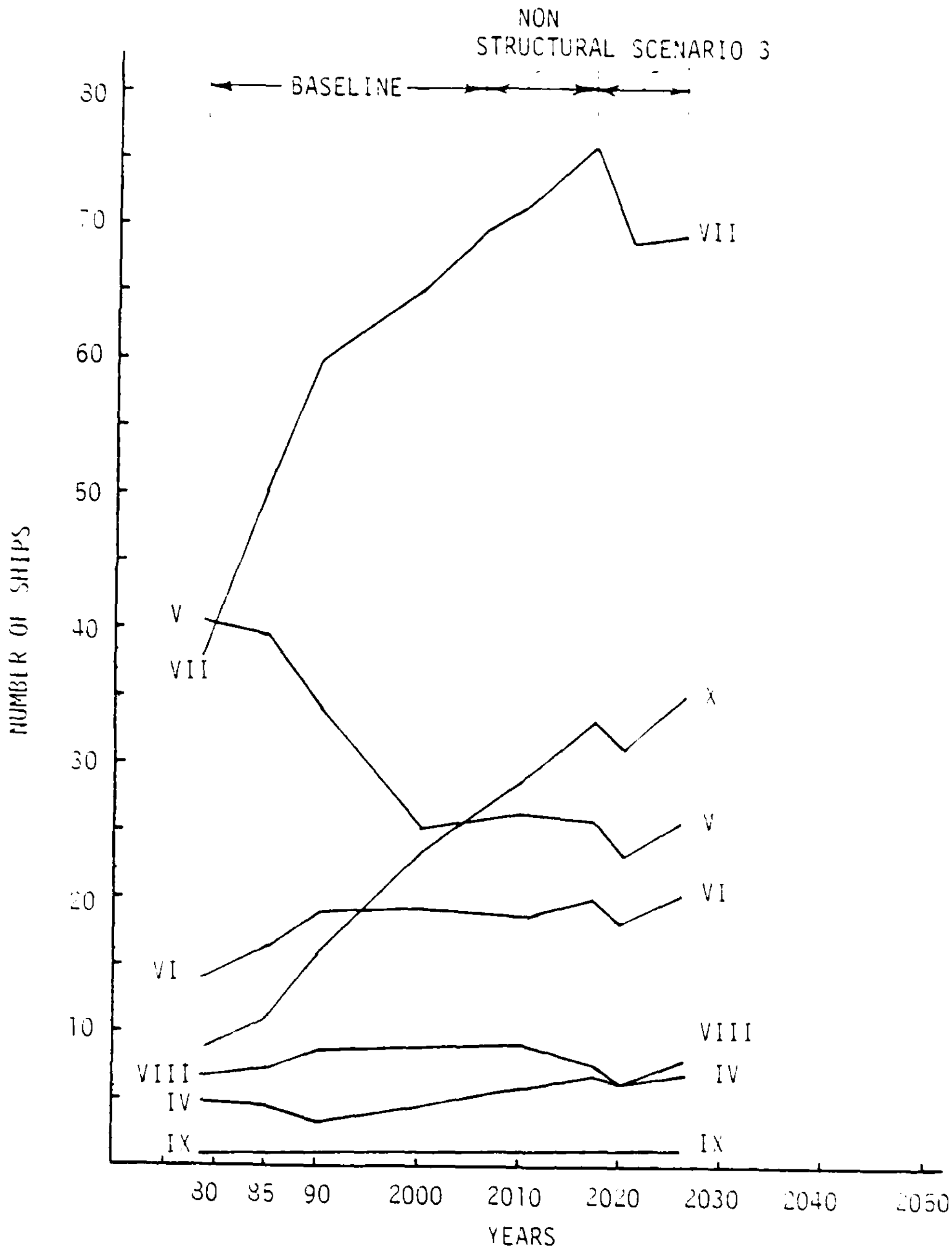

FIGURE 7.17 FLEET MIX, SOO LOCKS - SCENARIO 3 PLUS BASELINE AND NON-STRUCTURAL TO MAXIMUM UTILITY

November. During the most congested month, May, the lock utilization was 92.0%, average vessel waiting time was 4.0 hours upbound and 14.9 hours downbound, and average queue length was 1.2 vessels upbound and 5.3 vessels downbound. Lock utilization, vessel waiting time, and vessel queue length for the Poe Lock are shown on Figure 7.18.

The MacArthur Lock was not at capacity in 2026 with an average utilization of 79.0%. Because of building trends and vessel retirements, the number of vessels that could use the MacArthur Lock decreased. Lock utilization, vessel waiting time, and vessel queue length for the MacArthur Lock are shown on Figure 7.19.

7.6.2.2 Welland Canal - With an allowable ship draft of 28 feet and non-structural alternatives implemented to maximum utility, capacity at the Welland Canal was reached in 2012. The cargo passed through the locks at capacity in 2012 was 102,558,000 short tons. This was an increase of 13,960,000 short tons or 15.8% over the 88,598,000 short tons of cargo passed at capacity with only the non-structural alternatives to maximum utility in 1996.

The commodities that increased at the highest rates between 1996 and 2012 were other bulk, general cargo, and iron ore. Other bulk increased 22.4%, general cargo increased 21.4%, and iron ore increased 20.0%. Grain increased significantly between 1996 and 2012 although at a lower rate of 11.6%.

The Welland Canal fleet increased 1.6%, from 147.0 ships in 1996 to 149.4 ships in 2012. The composite ships class did not change, remaining at 6.2, therefore capacity was not inreased by use of larger ships. The Welland Canal fleet mix is shown on Figure 7.20.

The total number of transits through the Welland Canal increased slightly from 8,075 transits in 1996 to 8,119 transits in 2012. The ratio of loaded transits to total transits increased from 63.9% in 1996 to 65.2% in 2012, resulting in a capacity increase due to a reduction in the percentage of ballasted transits.

The constraining lock at the Welland Canal in 2012 had an average lock utilization of 91.7% during the peak months of May through November. During the most congested month, July, lock utilization was 97.0%, average vessel waiting time was 20.9 hours upbound and 10.2 hours downbound, and average queue

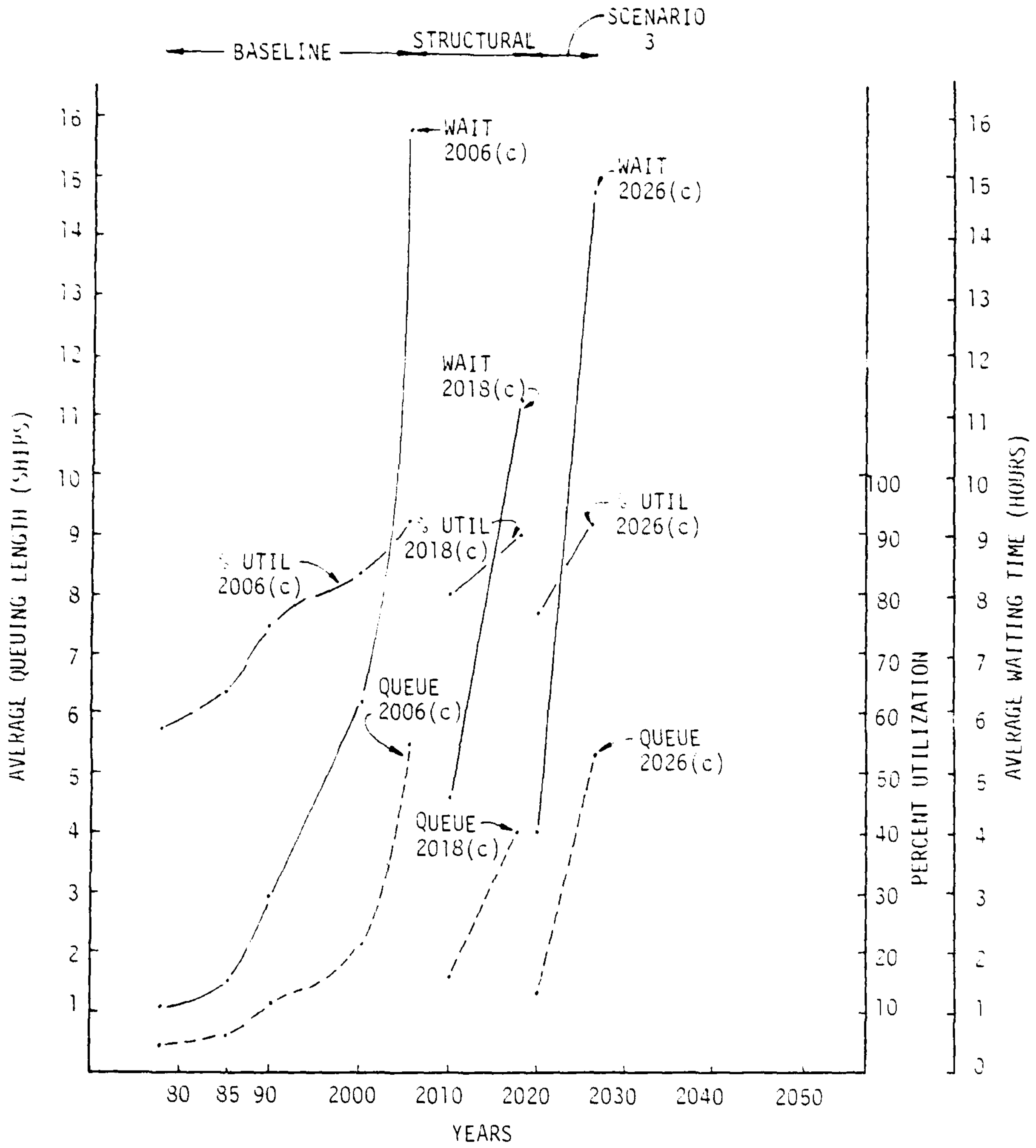

FIGURE 7.18 SCENARIO 3, POE LOCK - QUEUE LENGTH, WAITING TIME, % UTILIZATION

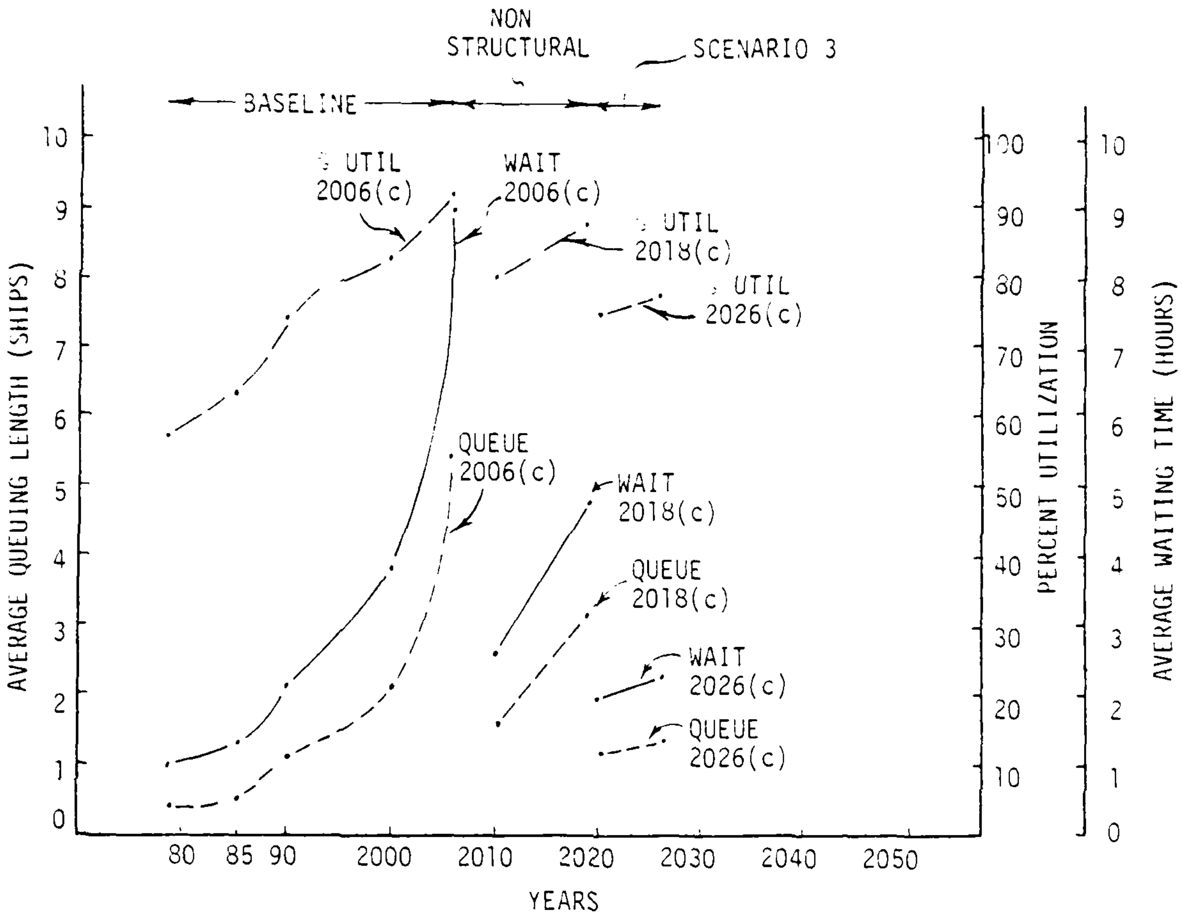

FIGURE 7.19 SCENARIO 3, MACARTHUR LOCK - QUEUE LENGTH, WAITING TIME, % UTILIZATION

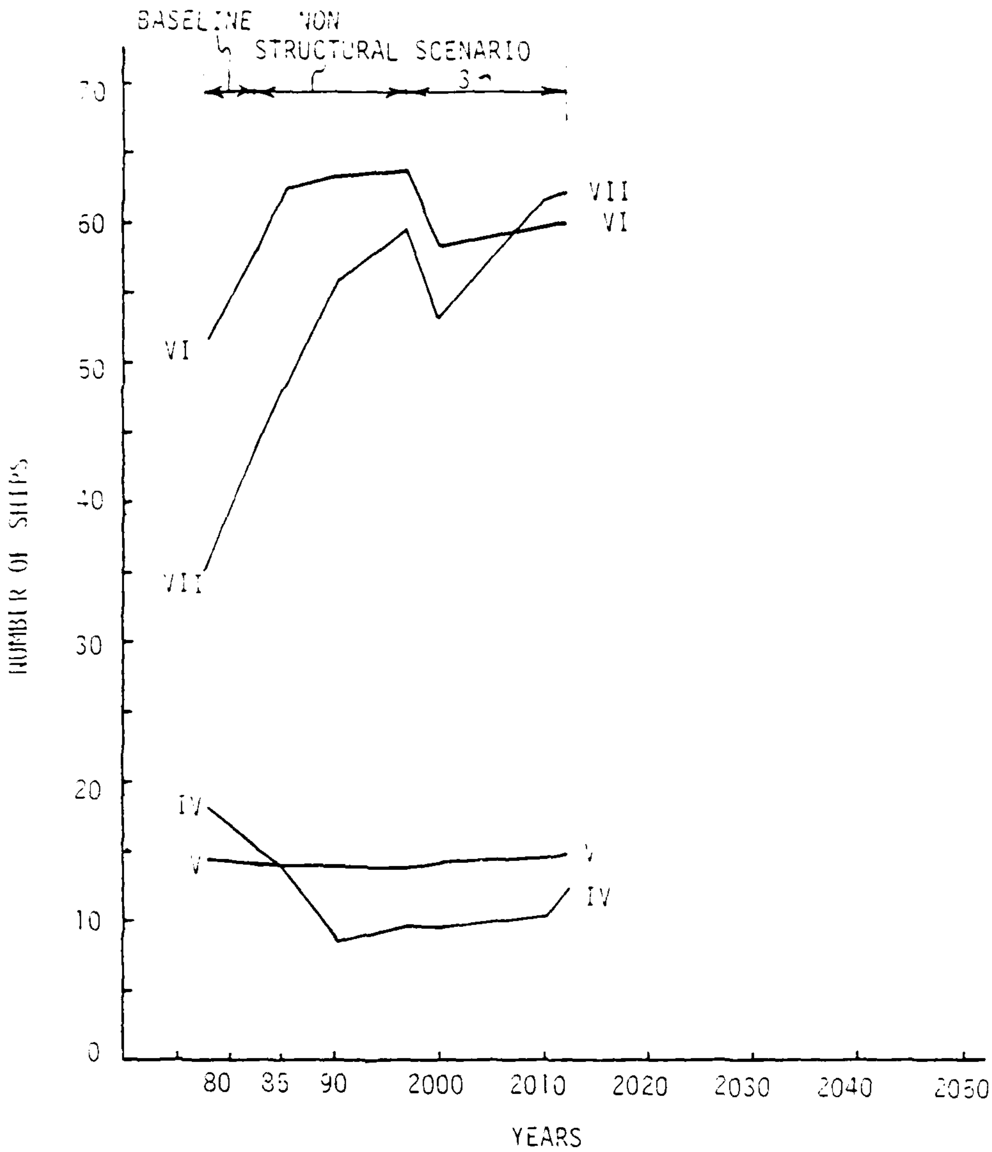

FIGURE 7.20 FLEET MIX, WELLAND CANAL - SCENARIO 3 PLUS BASELINE AND NON-STRUCTURAL TO MAXIMUM

length was 15.8 vessels upbound and 7.7 vessels downbound. Lock utilization, average vessel waiting time, and average queue length are shown on Figure 7.21.

7.6.2.3 St. Lawrence River - With non-structural alternatives implemented to maximum utility and an allowable ship draft of 28.0 feet, capacity was reached at the St. Lawrence River Locks in 2034. Increasing draft to 28.0 feet increased capacity to 122,945,000 short tons, a 14,348,000 short tons or 13.2% increase over the 108,597,000 short tons passed at capacity in 2024 with only non-structural alternatives to maximum utility.

The largest percentage increases in commodity tonnage were in general cargo and other bulk. General cargo increased 32.7%, and other bulk increased 14.9%. Large tonnage increases also occurred in grain which increased 8.1% and iron ore which increased 9.9%.

The St. Lawrence River fleet increased 2.8% from 179.2 ships in 2024 to 184.3 ships in 2034. The composite ship class dropped from 6.1 to 6.0 as the large increase in general cargo caused an increase in the number of Class 4 and 6 ships added to the fleet. The St. Lawrence River fleet mix is given on Figure 7.22.

The total number of transits through the St. Lawrence River increased slightly from 9,345 in 2024 to 9,404 in 2034. The ratio of loaded transits to total transits increased somewhat from 69.9% in 2024 to 71.1% in 2034, causing an increase in capacity due to a reduction in the percentage of ballasted transits.

At capacity in 2034, lock utilization was an average of 93.3% over the peak months from May through November. During the most congested month, July, lock utilization was greater than 98%, average vessel waiting time was 27.2 hours upbound and 27.5 hours downbound, and average queue length was 24.2 ships both upbound and downbound. Lock utilization, average vessel waiting time, and average queue length are given on Figure 7.23.

7.7 Scenario No. 4 - 32.0 Foot Draft

7.7.1 Scenario Description

At each lock system, as capacity was reached with non-structural alternatives combined to maximum utility, the capacity

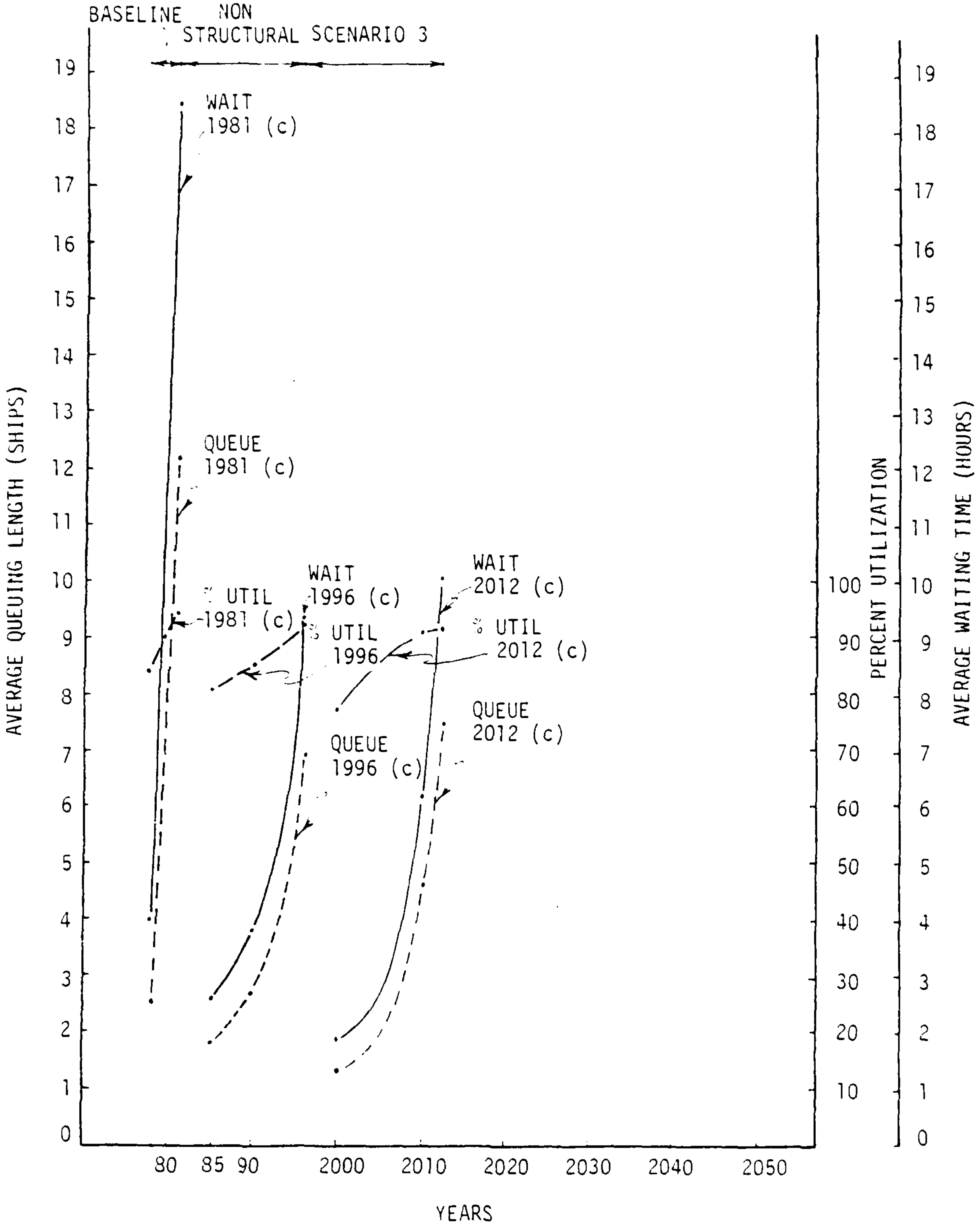

FIGURE 7.21 SCENARIO 3, WELLAND CANAL QUEUE LENGTH, WAITING TIME, % UTILIZATION

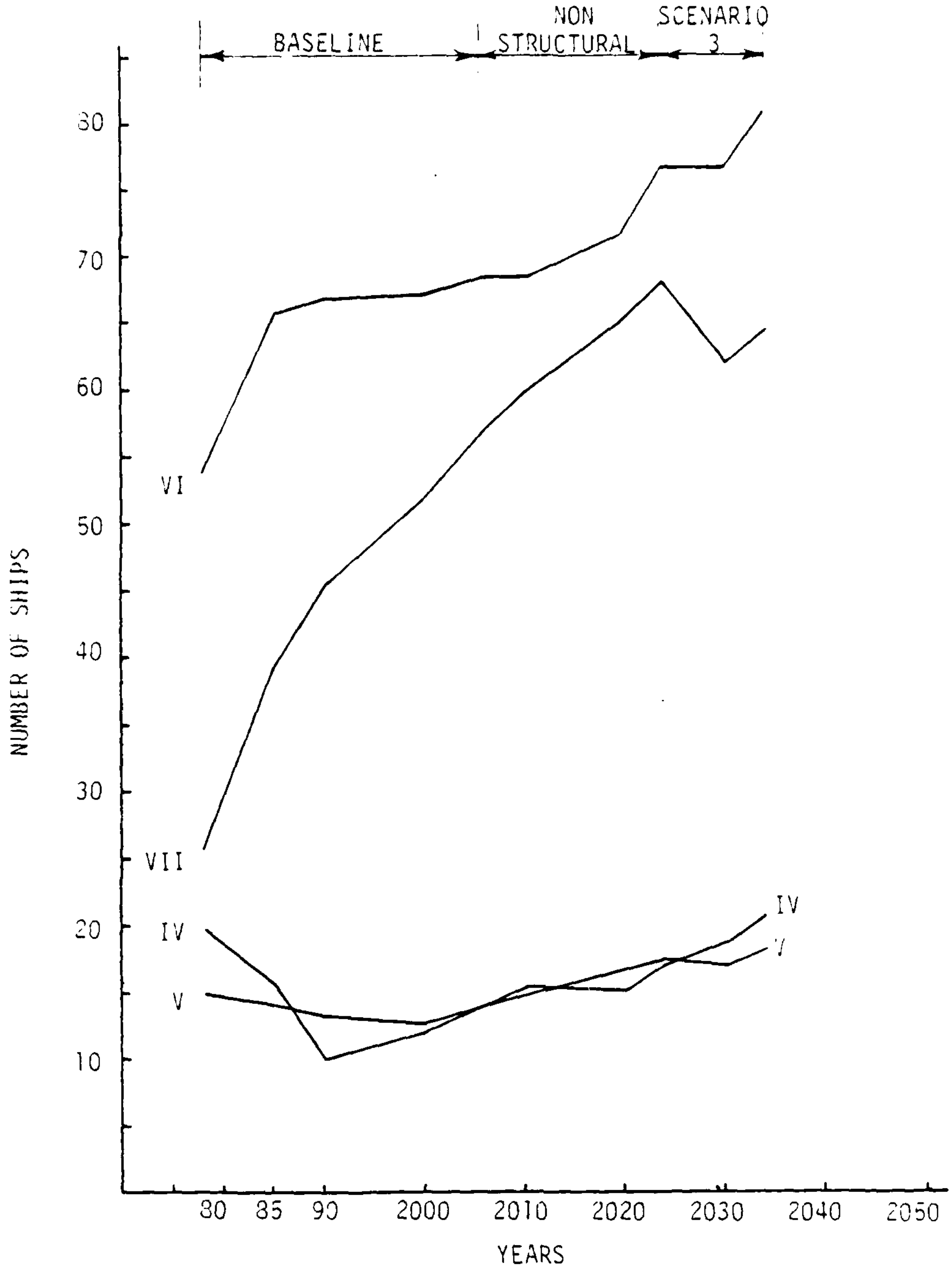

FIGURE 7.22 FLEET MIX, ST. LAWRENCE RIVER - SCENARIO 3 PLUS BASELINE AND NON-STRUCTURAL TO MAXIMUM UTILITY

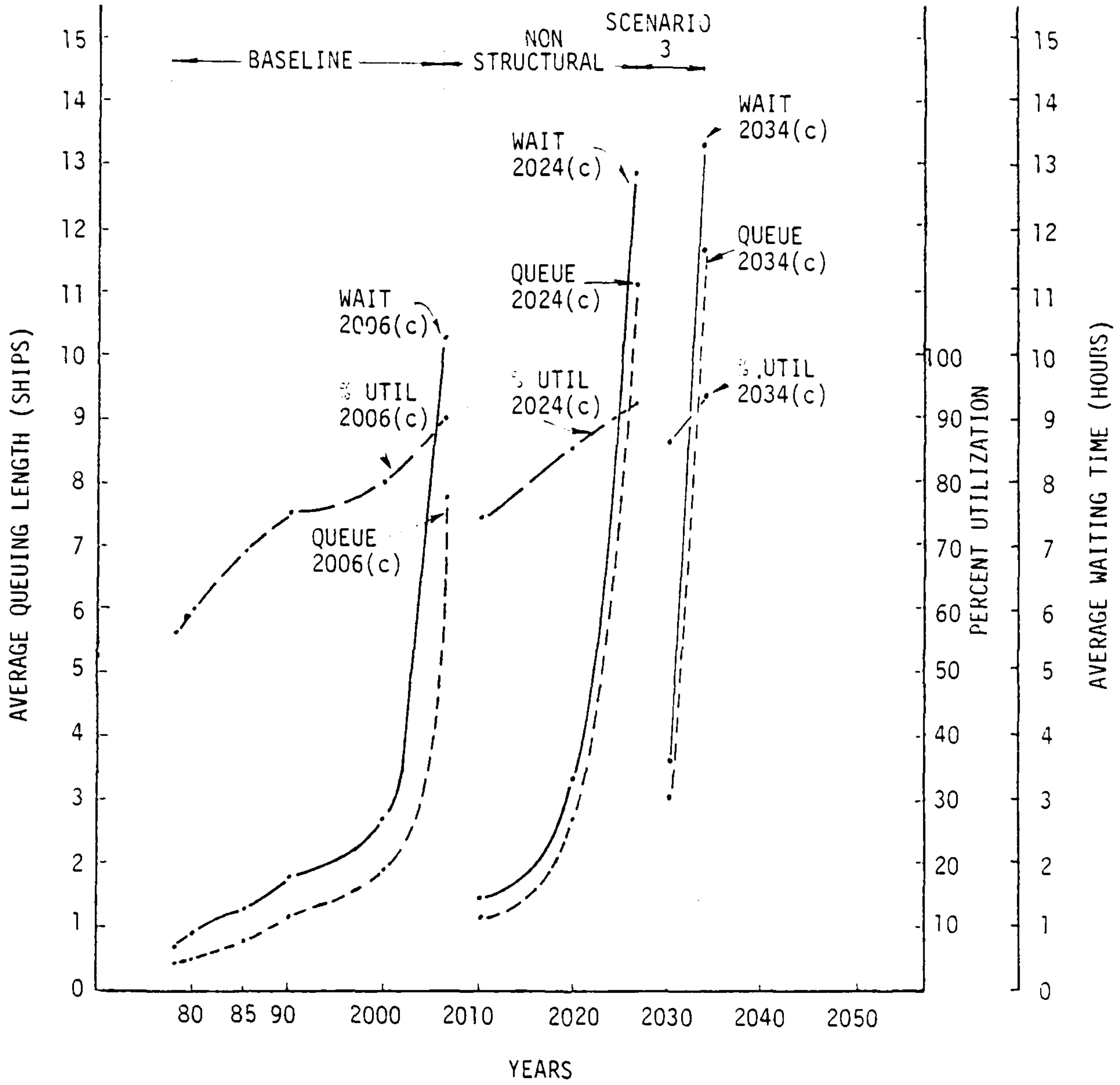

FIGURE 7.23 SCENARIO 3, ST. LAWRENCE RIVER - QUEUE LENGTH, WAITING TIME, % UTILIZATION

of the lock system was increased by increasing allowable ship draft to 32.0 feet. Drafts were not increased at the Sabin or Davis Locks because they mainly handle ballasted ships. No other change was made in the size of the locks. Maximum vessel class was still Class 10 at the Soo Locks and Class 7 at the Welland and St. Lawrence River Locks.

Increasing ship draft increases lock capacity by increasing the carrying capacity of each ship. Some ships, however, do not have sufficient molded depth to operate at deeper drafts. These are mainly the small lake ships. In the Lock Capacity Model, Class 4 ships were assumed to be operating at their maximum draft with system draft equal to 25.5 feet. The capacity of Class 4 ships was not increased for deeper drafts. The capacity of the other class ships were increased by the values tabulated for capacity increase per inch of immersion. The capacity increase per inch of immersion figures are given as part of Table 5.1.

7.7.2 Results of Lock Capacity Analysis

7.7.2.1 Soo Locks - With non-structural alternatives combined to maximum utility and a 32.0 foot operating draft, capacity was reached at the Soo Locks in 2038. The amount of cargo passed through the Soo at capacity in 2038 was 241,652,000 short tons. This was an increase of 44,886,000 short tons or 22.8% over the 196,766,000 tons of cargo passed through the Soo in 2018 when capacity was reached with non-structural alternatives implemented to maximum utility.

The increases in commodities between 2018 and 2038 were mainly in iron ore and grain. Iron ore increased 27.3% and grain increased 17.3%.

The total number of ships in the Soo fleet decreased 4.4%, from 169.3 ships in 2018 to 161.9 ships in 2038. The composite ship class remained the same at 7.1. However, the number of Class 4 and Class 10 ships increased while the number of ships in the intermediate classes decreased. Class 4 increased due to increases in other bulk. Class 10 increased due to increases in iron ore. The Soo fleet mix is shown in Figure 7.24.

The total number of transits through the Soo Locks decreased 10.4% from 11,807 transits in 2018 to 10,581 transits in 2038, as the increased ship capacities covered the increased tonnages. The ratio of loaded transits to total transits

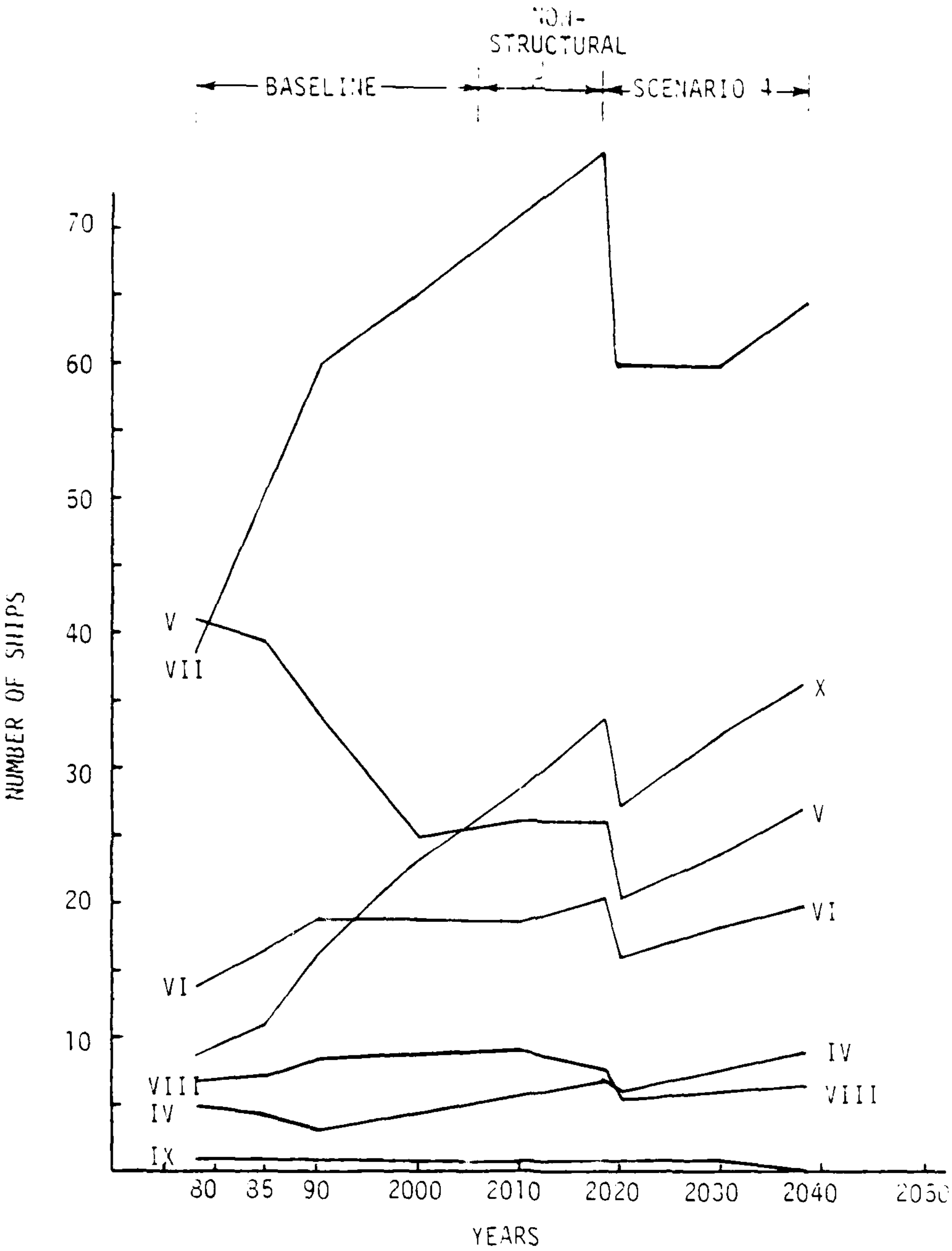

FIGURE 7.24 FLEET MIX, SOO LOCKS - SCENARIO 4
PLUS BASELINE AND NON-STRUCTURAL
TO MAXIMUM UTILITY

increased slightly from 56.1% in 2018 to 56.7% in 2038, causing a slight capacity increase.

At capacity in 2038, the average lock utilization for the Poe Lock for the peak months of May through November was 90.0%. During the most congested month, May, lock utilization was 90.0%, average vessel waiting time was 3.7 hours upbound and 11.3 hours downbound, and average queue length was 1.1 ships upbound and 4.0 ships downbound. Lock utilization, average vessel waiting time, and average queue length are shown in Figure 7.25.

Lock utilization at the MacArthur Lock in 2038 was 71% for May through November. Utilization of the MacArthur Lock decreased as the number of ships able to utilize that lock decreased. Lock utilization, average vessel waiting time, and average queue length are given in Figure 7.26.

7.7.2.2 Welland Canal - With non-structural alternatives combined to maximum utility and a draft of 32.0 feet, capacity was reached at the Welland Canal in 2030. The tonnage passed through the Welland Canal at capacity in 2030 was 122,586,000 short tons. This is an increase of 33,988,000 short tons or 38.4% over the 88,958,000 short tons passed through the canal in 1996 when capacity was reached with the non-structurals implemented to maximum utility.

The largest percentage increases in commodities were in general cargo, other bulk, and iron ore. General cargo increased 48.1%, other bulk increased 55.3%, and iron ore increased 46.4%. Grain also increased significantly although at a lower rate by 28.4%.

The number of ships in the Welland Canal fleet increased by 9.9%, from 147.0 ships in 1996 to 161.6 ships in 2030. The composite ship size decreased from 6.2 to 6.1 as small lakers and ocean-going ships were added to carry the increased other bulk and general cargo. This decreased fleet ship size resulted in a small decrease in capacity. The Welland Canal fleet mix is shown in Figure 7.27.

The number of transits through the Welland Canal increased 1.5%, from 8,075 ships in 1996 to 8,197 ships in 2030. At the same time the ratio of loaded transits to total transits increased from 63.9% to 66.5% due to an increase in upbound traffic relative to downbound traffic. This increased transit ratio resulted in increased capacity.

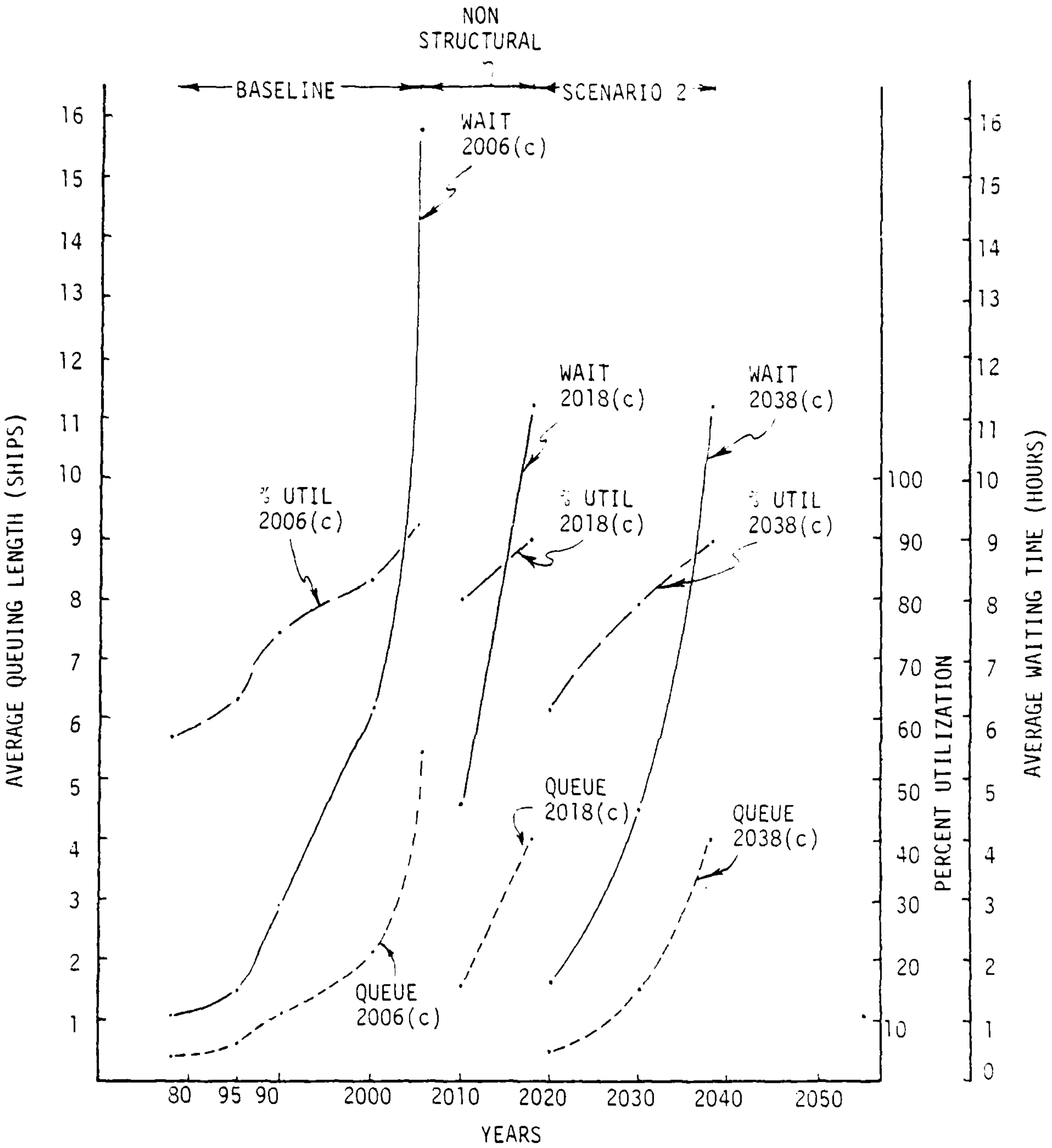

FIGURE 7.25 SCENARIO 4, POE LOCK - QUEUE LENGTH, WAITING TIME, % UTILIZATION

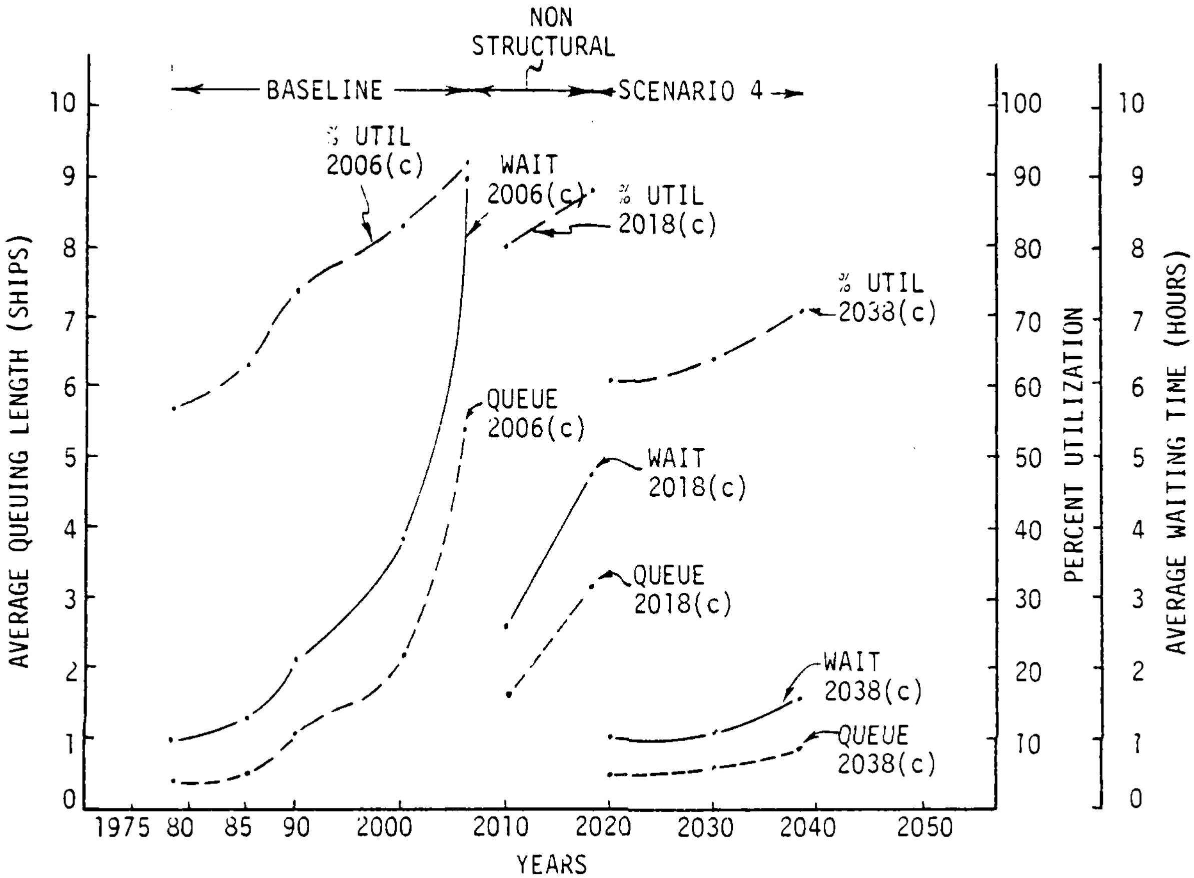

FIGURE 7.26 SCENARIO 4, MACARTHUR LOCK - QUEUE LENGTH, WAITING TIME, % UTILIZATION

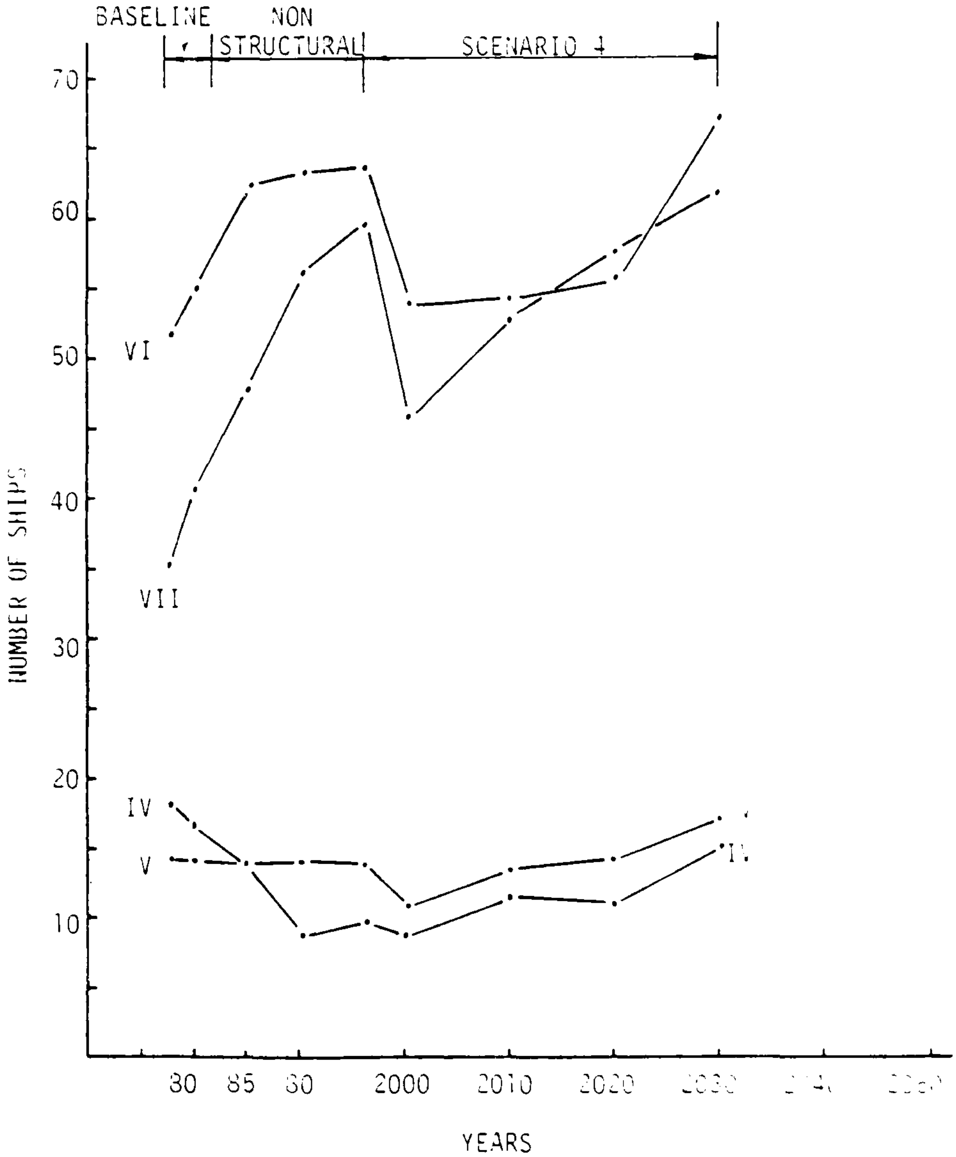

FIGURE 7.27 FLEET MIX, WELLAND CANAL - SCENARIO 4 PLUS BASELINE AND NON-STRUCTURAL TO MAXIMUM UTILITY

At capacity in 2030, lock utilization at the constraining lock on the Welland Canal was 92.7% for May through November. During the peak month of July, lock utilization was greater than 98.0%, average vessel waiting time was 27.6 hours upbound and 11.2 hours downbound, and the average queue length was 21.2 ships upbound and 8.6 ships downbound. Lock utilization, average vessel waiting time, and average queue length are given in Figure 7.28.

7.7.2.3 St. Lawrence River - Capacity was reached in 2046 in the St. Lawrence River Locks with operating draft equal to 32 feet and non-structural alternatives implemented to maximum utility. The amount of cargo processed through the St. Lawrence River Locks at capacity in 2046 was 141,885,000 short tons. This is an increase of 33,288,000 short tons or 30.7% over the 108,597,000 short tons of cargo processed through the St. Lawrence River Locks in 2024 when capacity was reached with non-structural alternatives implemented to maximum utility.

General cargo increased the most between 2024 and 2046, increasing 71.7% from 15,144,000 short tons in 2024 to 26,005,000 short tons in 2046. Also increasing significantly were other bulk increasing by 35.4%, iron ore increasing by 23.4%, and grain increasing by 19.5%.

The St. Lawrence River fleet increased 8.0%, from 179.2 ships in 2024 to 193.6 ships in 2046. The composite ship decreased from 6.1 to 6.0, because of the large increases in other bulk and general cargo which are transported in ocean-going ships and small lakers. The reduced fleet ship size resulted in a decreased capacity. The St. Lawrence River fleet mix is shown in Figure 7.29.

The total number of transits through the St. Lawrence River decreased 1.3%, from 9,345 transits in 2024 to 9,226 transits in 2046. The ratio of loaded transits to total transits increased from 69.9% to 72.1% because of a more even balance between upbound and downbound commodities. An increase in capacity resulted because of a reduction in the percentage of ballasted transits.

The constraining lock on the St. Lawrence River had an average lock utilization of 90.0% in 2046 during the months of May through November. During July, the most congested month, lock utilization was 97.0%, average vessel waiting time was 15.9 hours upbound and 13.5 hours downbound, and average queue length was 14.1 ships upbound and 12.0 ships downbound. Lock utilization, average vessel waiting time, and average queue length are given in Figure 7.30.

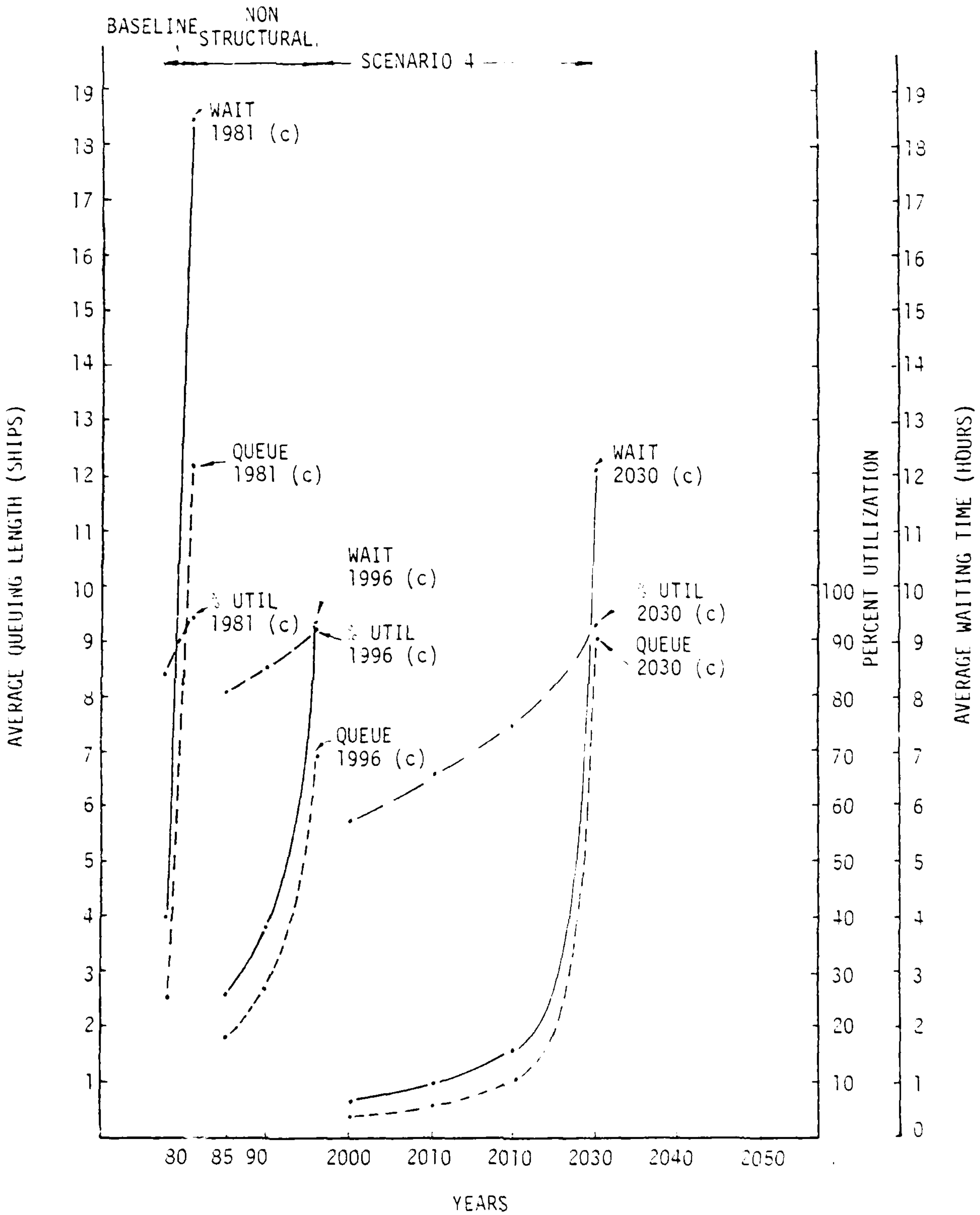

FIGURE 7.28 SCENARIO 4, WELLAND CANAL QUEUE LENGTH, WAITING TIME, UTILIZATION

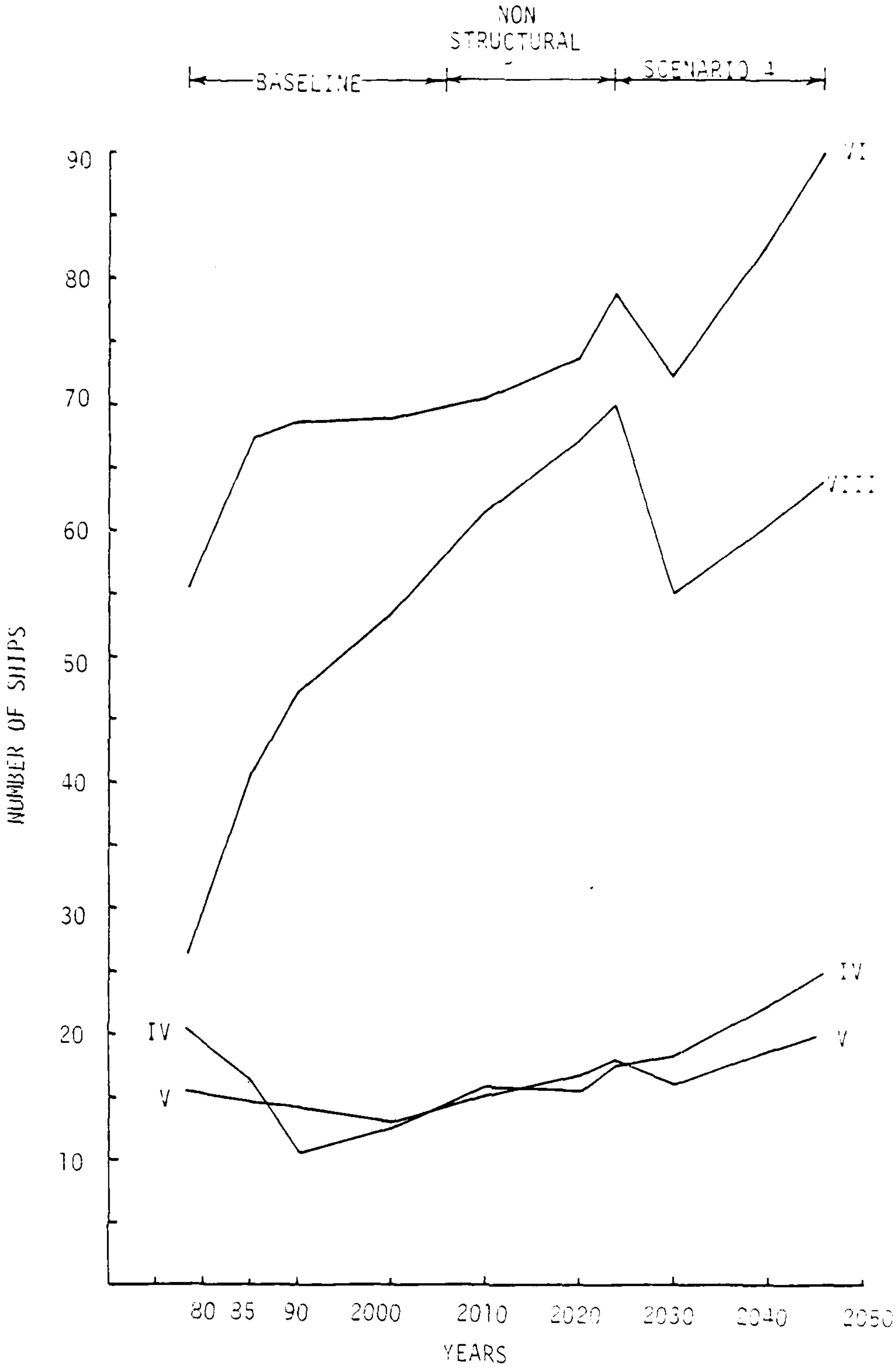

FIGURE 7.29 FLEET MIX, ST. LAWRENCE RIVER - SCENARIO 4 PLUS BASELINE AND NON-STRUCTURAL TO MAXIMUM UTILITY

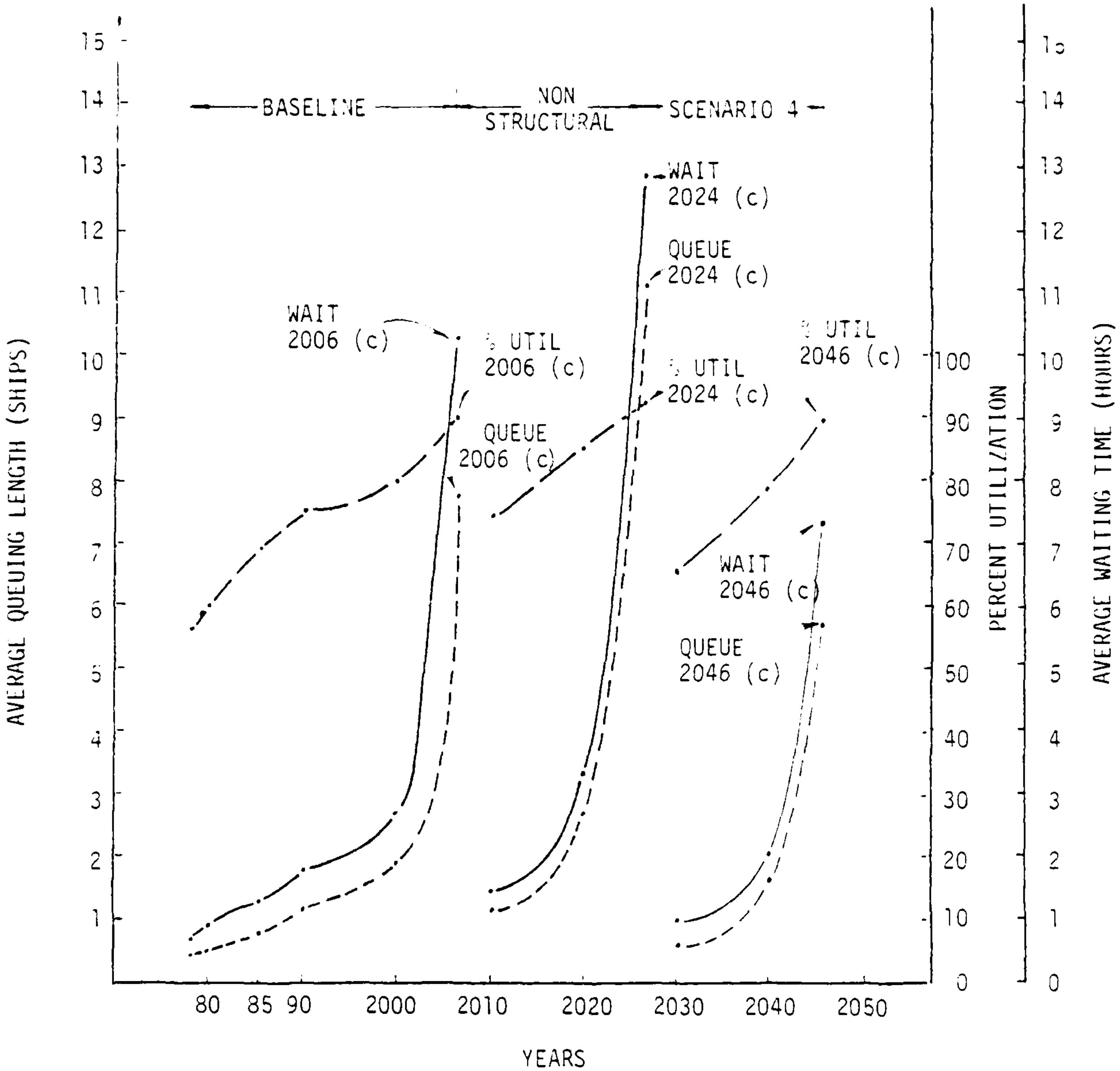

FIGURE 7.30 SCENARIO 4, ST. LAWRENCE RIVER QUEUE LENGTH, WAITING TIMES, % UTILIZATION

7.8 Scenario No. 5 - Constrained Cargo Flows

7.8.1 Scenario Description

In this scenario the only improvements to the Welland Canal and St. Lawrence River portions of the GL/SLS System are non-structural. With non-structural improvements combined to maximum utility, the Welland Canal reached capacity in 1996. No alternatives were implemented at the Welland Canal past 1996 to relieve this capacity condition. Instead, the Welland Canal was allowed to constrain the cargo flow through the GL/SLS System. Non-structural alternatives were implemented at the Soo and St. Lawrence River Locks when they reached capacity. A 1350 by 115 foot lock was placed in operation at the Soo when capacity was reached there with non-structural alternatives combined to maximum utility.

The new lock at the Soo was built as in Scenario No. 1. The Davis Lock was replaced by a 1350 by 115 foot lock capable of handling Class 11 ships. The Sabin, MacArthur, and Poe Locks remained unchanged structurally. Non-structural alternatives were also implemented on the new Davis Locks.

7.8.2 Cargo Forecasts

A capacity tonnage of 87,400,000 short tons was reached in 1996 at the Welland Canal with non-sttuctural alternatives implemented to maximum utility. This tonnage was assumed to be the maximum tonnage that may be passed through the Welland Canal, and therefore the Welland Canal cargo projections were held constant at 87,400,000 short tons from 1996 to 2050. The cargo flows for the Soo and St. Lawrence River were recalculated by the Corps [10] based on a maximum tonnage through the Welland Canal of 87,400,000 short tons. The constrained cargo forecasts are shown on Figure 7.31.

7.8.3 Results of Capacity Analysis

7.8.3.1 Soo Locks - Using the cargo forecasts constrained by the capacity condition at the Welland Canal in 1996, the existing Soo Locks reached capacity in 2008 at a tonnage of 173,483,000 short tons. By implementing non-structural alternatives to maximum utility, capacity at the Soo Locks was postponed to 2020 with a cargo volume of 191,944,000 short tons. By constructing a new Davis Lock capable of handling Class 11 ships, the Soo Locks passed the 2050 constrained cargo flows. The tonnage passed through the Soo in 2050 is 248,051,000 short tons.

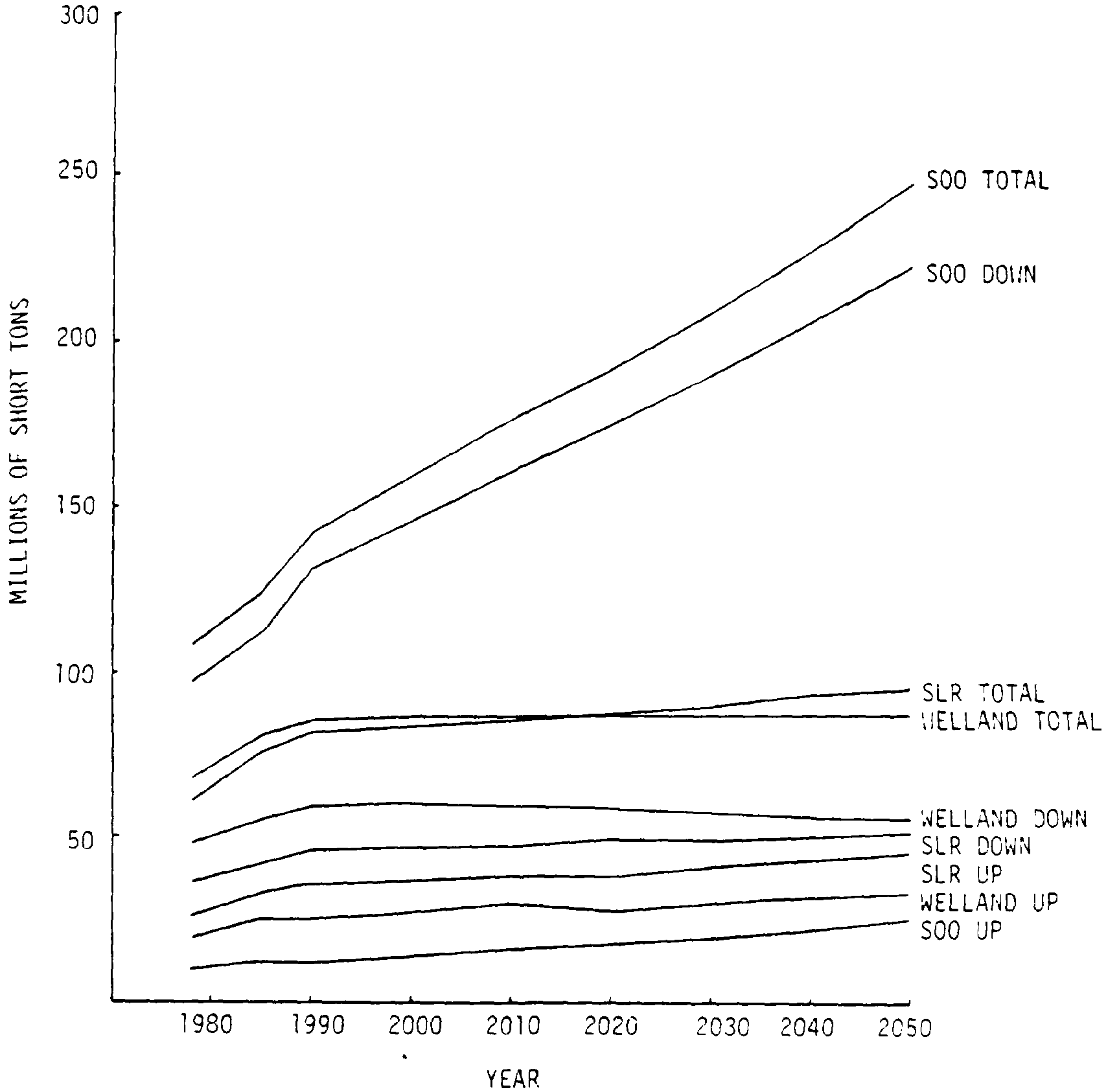

FIGURE 7.31 CARGO FLOWS CONSTRAINED BY A CAPACITY CONDITION AT THE WELLAND IN 1996

The 2050 cargo tonnage is 24,194,000 short tons or 8.9% less than the unconstrained 2050 cargo projection of 272,245,000 short tons. The cargos that decreased significantly due to the constraint at the Welland Canal were grain and other bulk. Grain decreased 38.2% from an unconstrained total of 52,413,000 short tons to a constrained total of 32,368,000 short tons. Other bulk decreased 13.2% from 13,820,000 short tons in the unconstrained forecast to 11,999,000 short tons in the constrained flow.

Using the constrained cargo flows, the Soo Locks were not at capacity in 2050. Average lock utilization was 65.9% at the Poe and MacArthur Locks and 65.3% at the new Davis Lock for the months of May through November.

There were 176.4 ships in the Soo fleet in 2050 using the constrained cargo forecasts. The composite ship size for the fleet was 7.4. This compares to capacity in 2050 with the unconstrained flows and a 1350 by 115 foot Davis Lock where there were 170.6 ships but with a composite ship class of 8.1. The number of Class 10 and 11 ships did not increase as much in this Scenario as they did in Scenario I because grain, which tends to be carried in the largest ships, had to be carried in Class 7 ships in order to pass through the Welland Canal and St. Lawrence River. The Soo fleet mix is shown on Figure 7.32.

The number of transits through the Soo Locks in 2050 with the constrained flows was 12,282 as compared with 11,379 transits with the unconstrained flows. This increase is another indication of the smaller fleet size. The ratio of loaded transits to total transits decreased from 58.9% for the unconstrained case to 57.7% for the constrained case, indicating that a greater percentage of upbound cargos were blocked by the Welland Canal constriction than downbound cargos.

Since the Soo Locks were not at capacity in 2050, waiting times and queue lengths were relatively short. At the MacArthur Lock during the month of June, lock utilization was 66.0%, average vessel waiting times were 0.5 hours upbound and 1.5 hours downbound, and average queue lengths were 0.1 ships upbound and 0.6 ships downbound. At the Poe Lock, utilization was 66.0% in June, average vessel waiting time was 0.8 hours upbound and 1.8 hours downbound, and average queue length was 0.2 ships upbound and 0.6 ships downbound. At the new Davis Lock in May, lock utilization was 67.0%, average vessel waiting time was 1.8 hours upbound and 2.6 hours downbound, and average

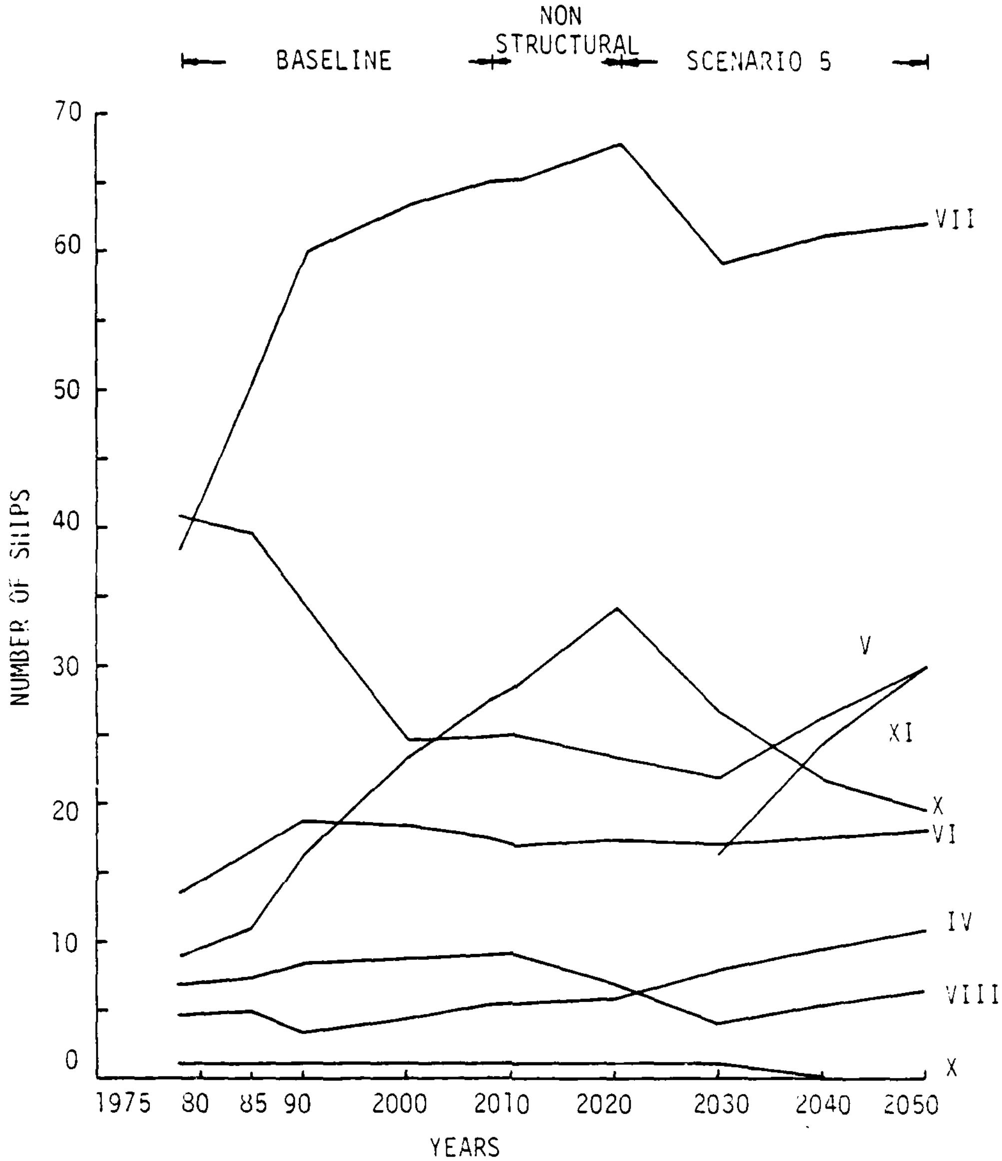

FIGURE 7.32 FLEET MIX, SOO LOCKS - SCENARIO 5
PLUS BASELINE AND NON-STRUCTURAL TO
MAXIMUM UTILITY

queue length was 0.4 ships upbound and 0.8 ships downbound. Lock utilization, average vessel waiting times, and average queue lengths for the MacArthur, Poe, and the new Davis Locks are shown on Figures 7.33, 7.34, and 7.35, respectively.

7.8.3.2 Welland Canal - Capacity was reached at the existing Welland Canal in 1981 with a cargo flow of 75,185,000 short tons. Non-structural alternatives to maximum utility were implemented extending the capacity of the Welland Canal to a cargo flow of 87,400,000 short tons. This tonnage, the maximum amount of cargo that would be processed through the Welland Canal without structural modifications, was reached in 1996 and was held constant through to 2050. In the year 1996 the Welland Canal was slightly below capacity with an average lock utilization for the peak months of May through November of 88.6%. This near capacity condition existed through 2050, dropping slightly to 85.4% by 2050.

The capacity constraint of 87,400,000 short tons through the Welland Canal blocked 67,934,000 short tons or 43.7% of the unconstrained 2050 Welland Canal cargo projections. This cargo restriction appeared across the board with the 2050 constrained forecast for each of the six commodity groups approximately 43.7% less than the 2050 unconstrained forecasts.

In 2050 with the constrained cargo projections the Welland Canal fleet consisted of 147.1 ships with a composite ship class of 6.1. The number of ships in the fleet increased slightly from 144.8 ships in 1996, but the composite ship class dropped slightly from 6.2 in 1996. The Welland Canal fleet mix is shown on Figure 7.36.

The reason for the capacity condition abating slightly between 1996 and 2050, despite the slight decrease in composite ship class, is that the loaded transits to total transits ratio increased significantly between 1996 and 2050. In 2050 67.5% of the 7,789 transits were loaded, while in 1996 only 64.2% of the 7,937 transits were loaded.

At 2050 a near capacity condition existed with average lock utilization during the peak months equal to 85.4%. During the monst congested month in 2050, July, lock utilization at the constraining lock was 90.0%, average vessel waiting time was 5.9 hours upbound and 4.3 hours downbound, and average queue length was 4.3 ships upbound and 3.2 ships downbound. Lock utilization, average vessel waiting time, and average queue length are given on Figure 7.37.

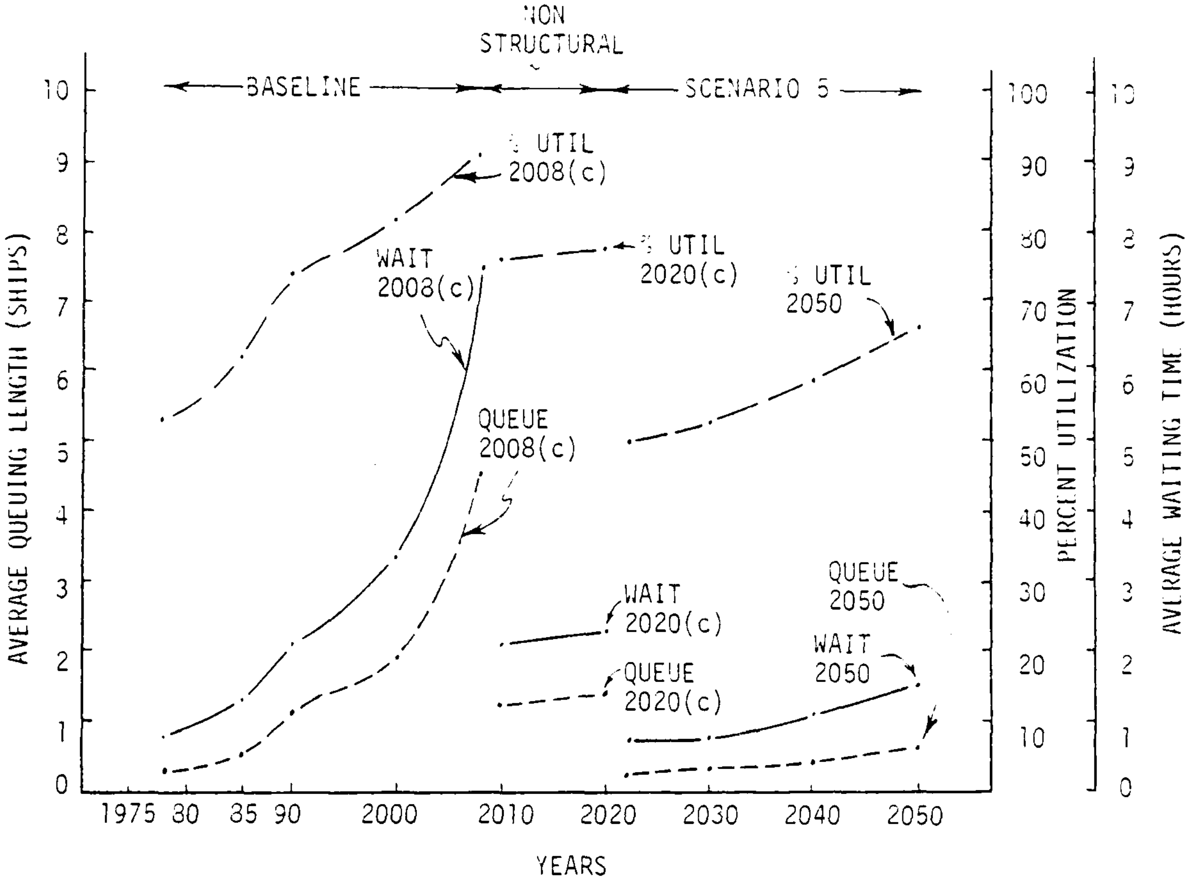

FIGURE 7.33 SCENARIO 5, MACARTHUR LOCK - QUEUE LENGTH, WAITING TIME, % UTILIZATION

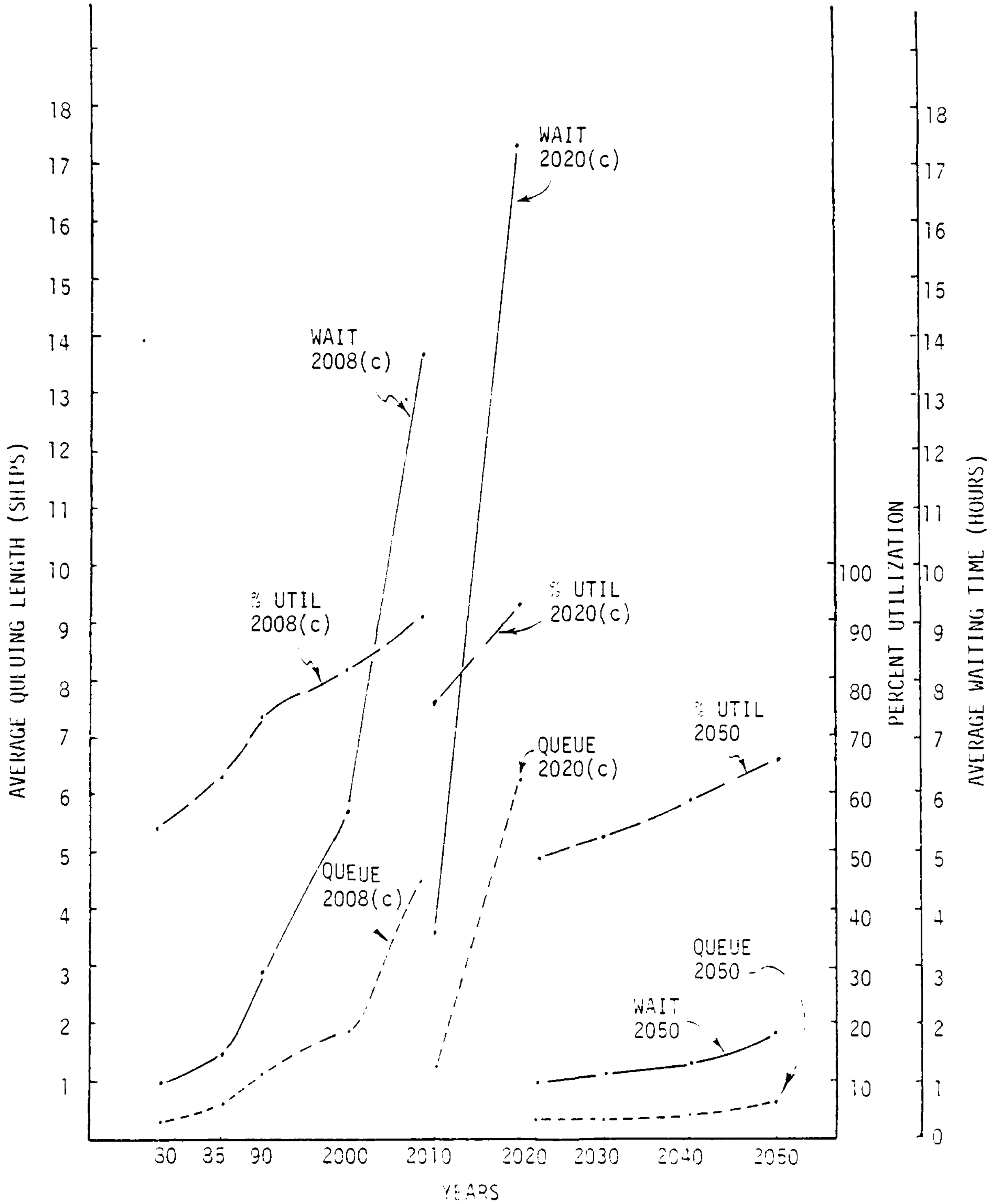

FIGURE 7.34 SCENARIO 5, POE DOCK - QUEUE LENGTH, WAITING TIME, UTILIZATION

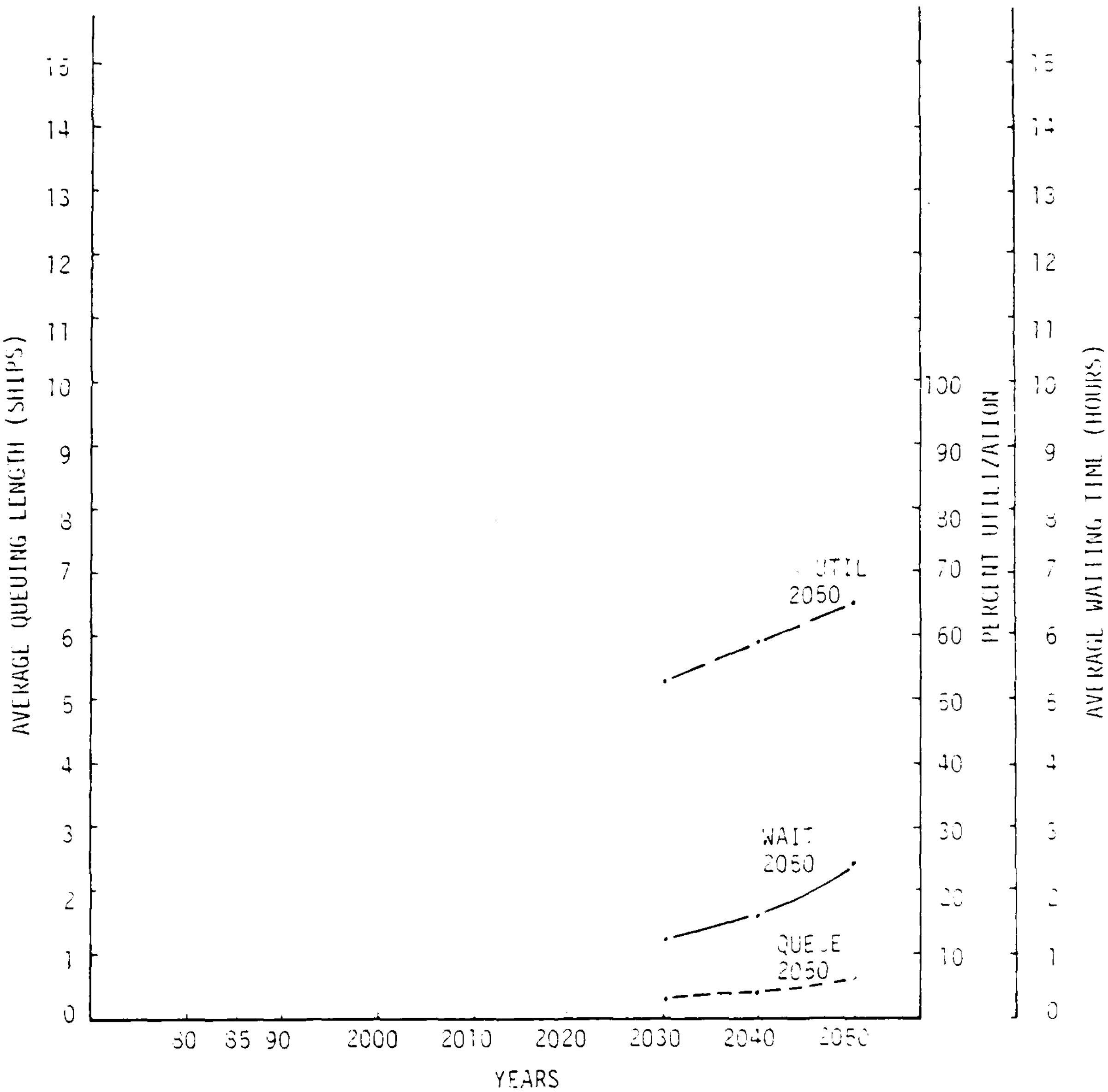

FIGURE 7.35 SCENARIO 5, NEW DAVIS LOCK - QUEUE LENGTH, WAITING TIME, UTILIZATION

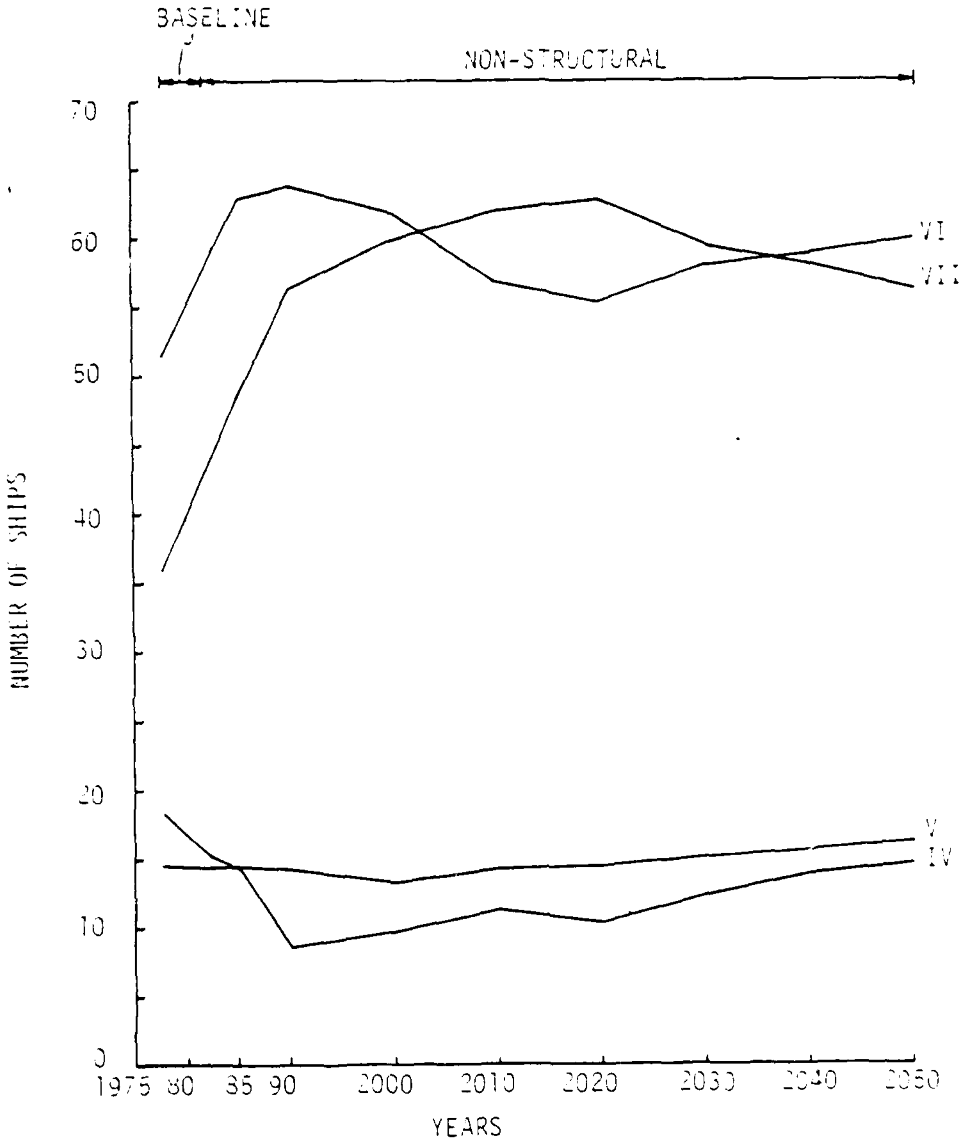

FIGURE 7.36 FLEET MIX, WELLAND CANAL - SCENARIO 5 PLUS BASELINE AND NON-STRUCTURAL TO MAXIMUM UTILITY

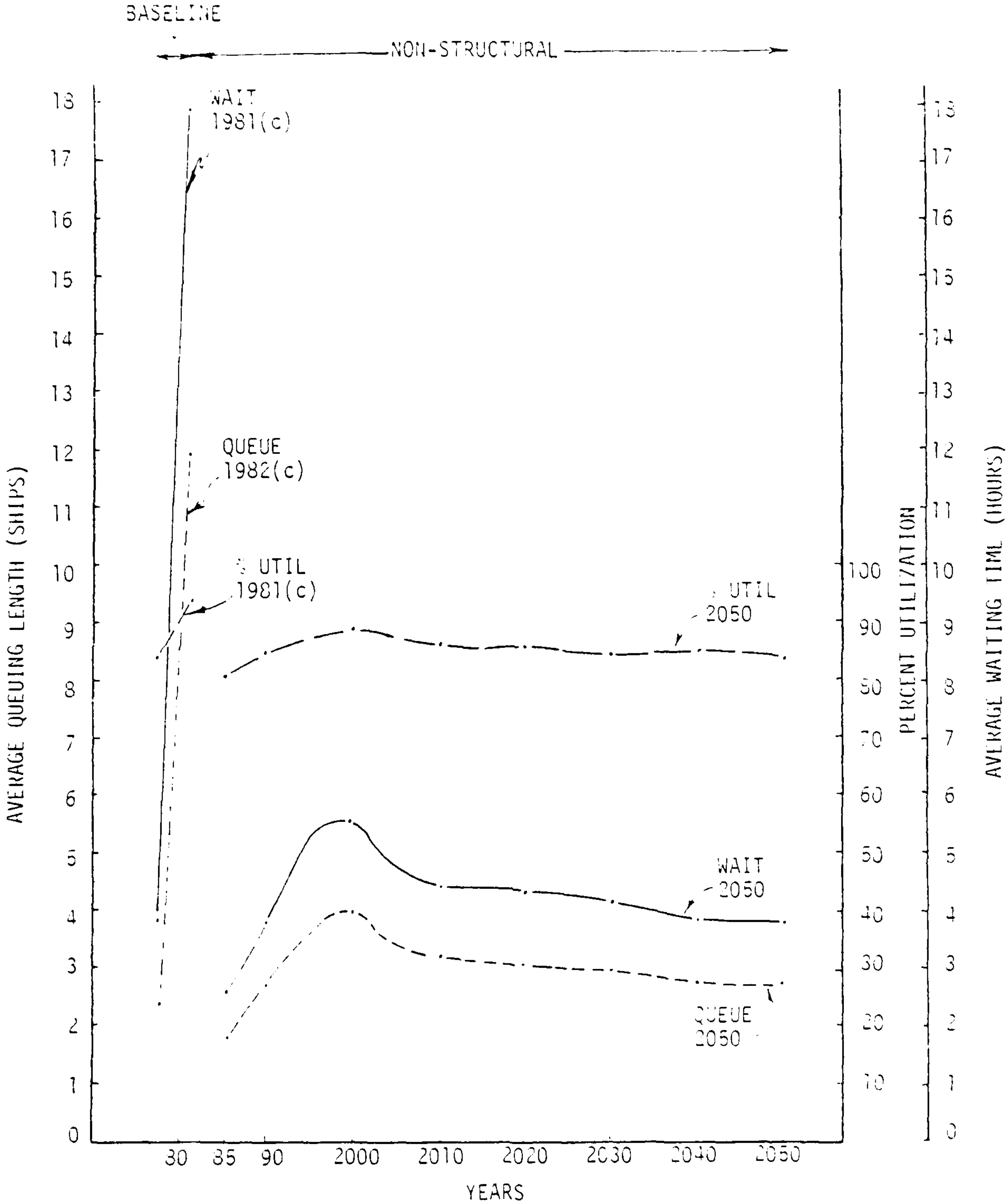

FIGURE 7.37 SCENARIO 5, WELLAND CANAL - QUEUE LENGTH, WAITING TIME, % UTILIZATION

7.8.3.3 St. Lawrence River - Using the cargo projections constrained by a capacity condition at the Welland Canal, capacity through the existing St. Lawrence River Locks was reached in 2050. By implementing the non-structural alternatives to maximum utility, capacity through the St. Lawrence River Locks was extended beyond 2050.

At 2050 the amount of cargo that passed through the St. Lawrence River Locks was 95,429,000 short tons. This constrained cargo flow is 52,830,000 short tons or 35.6% less than the unconstrained cargo flow of 148,259,000 short tons projected for the St. Lawrence River for 2050. The cargos that were affected the most by the Welland Canal constriction were grain, general cargo, iron ore, and other bulk. Grain decreased 41.2% from an unconstrained projection of 57,415,000 short tons to a constrained total of 33,734,000 short tons. General cargo was reduced 37.7% from 28,019,000 short tons in the unconstrained case to 17,469,000 short tons in the constrained case. Iron ore decreased 37.0% from an unconstrained flow of 33,015,000 short tons to a constrained flow of 20,789,000 short tons. Other bulk decreased 22.7% from an unconstrained 27,333,000 short tons to a constrained 21,116,000 short tons.

The St. Lawrence River Locks were not at capacity in 2050, with an average lock utilization of 74.9%. The St. Lawrence River fleet contained 159.4 ships in 2050 with a composite ship class of 6.0. The St. Lawrence fleet mix is shown on Figure 7.38. There were 3,303 transits through the St. Lawrence River in 2050, 72.5% of which were loaded.

The constraining lock on the St. Lawrence River System had a peak month lock utilization of 80.0%, average vessel waiting time of 2.1 hours upbound and 2.0 hours downbound, and average queue length of 1.6 ships both upbound and downbound. Lock utilization, average vessel waiting time, and average queue length are given in Figure 7.39

7.9 Summary of the Impact of Structural Alternatives on Lock Capacity

Subsections 7.4 through 7.8 of this report discussed in detail the impact of each of the structural scenarios on the capacity of the GL/SLS System. Fleet mix and queuing information of each lock system under each scenario were presented graphically. This section summarizes the results of these analyses and discussed the capacity expansion generated by each of the alternatives.

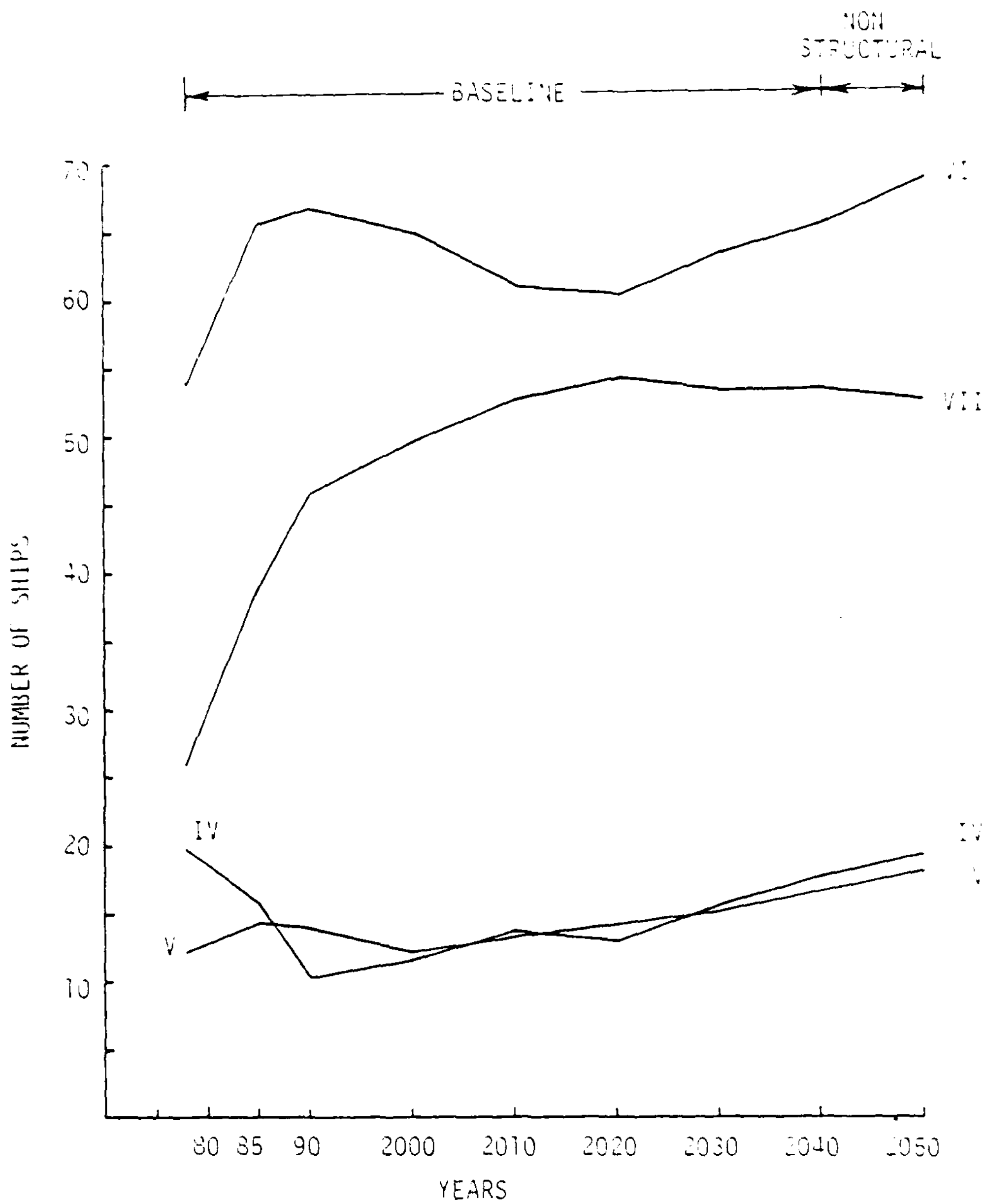

FIGURE 7.38 FLEET MIX, ST. LAWRENCE RIVER - SCENARIO 5 PLUS BASELINE AND NON-STRUCTURAL TO MAXIMUM UTILITY

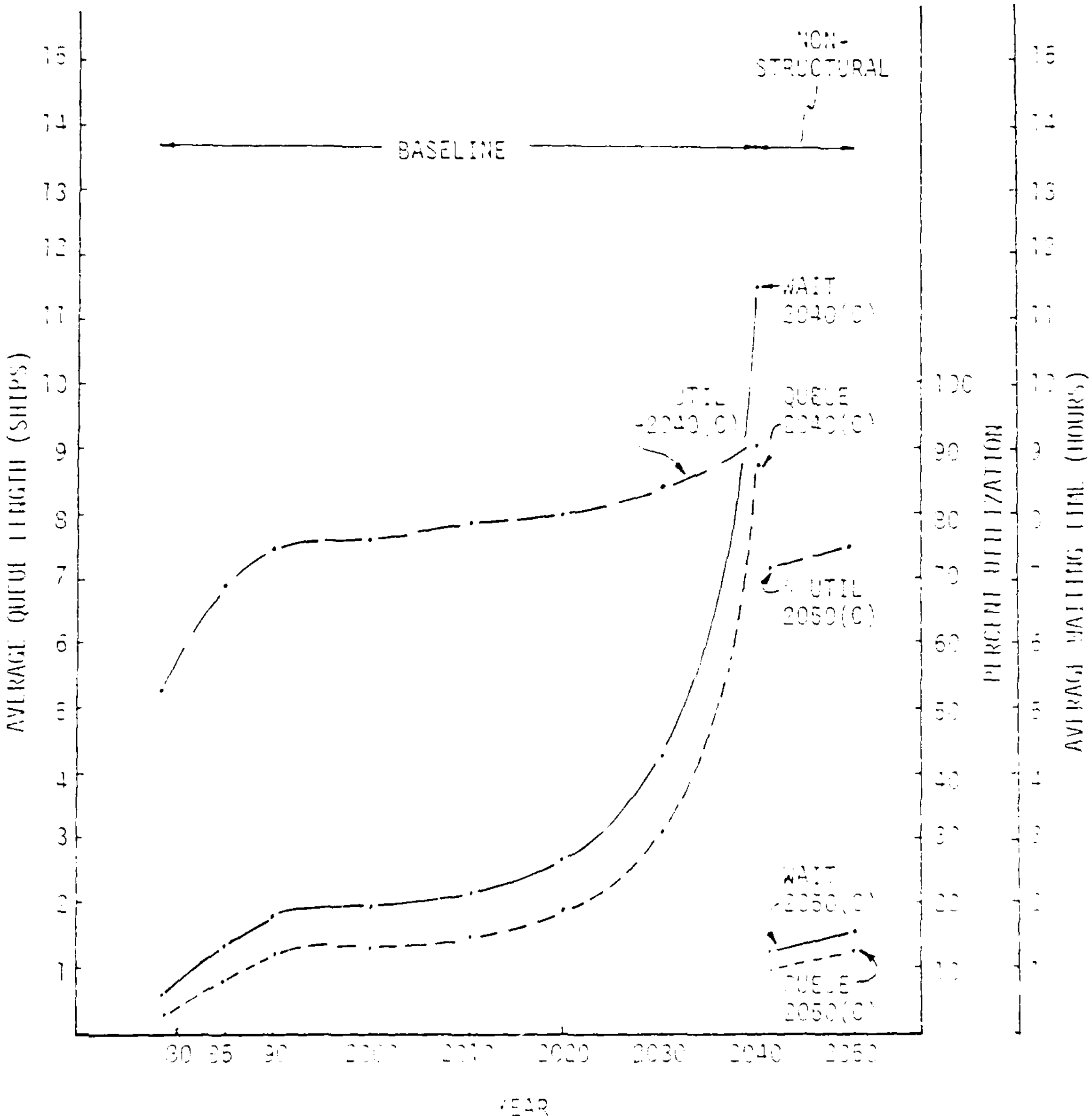

FIGURE 7.39 SCENARIO E, ST. LAWRENCE RIVER - QUEUE LENGTH, WAITING TIME, UTILIZATION

As with the non-structural alternatives, the amount of additional cargo tonnage which is processed through the locks as a result of implementing a structural change is probably the best overall indicator of the effectiveness of that change. Since three of the scenarios involve constructing new locks which can handle larger ships, the number of transits through a lock system is not a good indicator of capacity expansion due to these changes. This is because larger ships require more lockage time, decreasing the number of transits possible in a day. However, since larger ships transport more tonnage per minute of lockage than do smaller ships, capacity is increased despite a decrease in the number of transits. The parameters which best indicate the increase in capacity due to larger ship construction spurred by larger locks or by increased ship capacity due to deeper allowable drafts are the composite ship class and the tonnage transported per lockage.

Waiting time is a good indicator of lock capacity. Capacity expansion measures reduce waiting time. However, as the demand for service increased and lock system capacity is again approached, waiting times increase to the same levels that existed before the measure was implemented. In the interim, the lock system did serve its users effectively with below capacity conditions.

Tonnage composite ship class, and tonnage transported per lockage, along with the length of time the capacity condition is delayed, will be used as indicators to judge the relative effectiveness of the structural scenarios. These parameters are given on Table 7.11 for the Soo Locks, Table 7.12 for the Welland Canal Locks, and Table 7.13 for the St. Lawrence River Locks.

It can be seen from the summary tables that increasing lock size at 25.5 foot draft results in a larger increase in capacity than increasing draft but retaining the existing lock size. Both the 1350 by 115 foot locks and the 1460 by 145 foot locks of 25.5 foot draft increased lock capacity (tonnage) more than either a 28 foot or a 32 foot draft with the existing lock size.

Increasing lock size promotes the construction of larger ships which causes an increase in the composite ship size. Since larger ships have more carrying capacity, an increase in the number of large ships increases the tonnage processed per lockage. Increasing allowable ship draft without increasing lock size does not increase the number of large ships in the fleet. It increases the carrying capacity of the ships in the fleet, also increasing the tonnage per lockage.

TABLE 7.11 STRUCTURAL SCENARIO EFFECTIVENESS SUMMARY

Soo Locks

Structural Scenario	Capacity Year	Tonnage at Capacity (10^3 ST)	Composite Ship Class	Tonnage per Lockage (ST)
Non-Structural to Maximum Utility	2018	196,766	7.1	16,665
1350 by 115 ft Lock	2050	272,245	8.1	23,925
1460 by 145 ft Lock	Past 2050	272,247[a]	8.5[a]	27,684[a]
28 ft Draft	2026	213,734	7.1	19,174
32 ft Draft	2038	241,652	7.1	22,838
1350 by 115 ft Lock Constrained Cargo	Past 2050	248,051[a]	7.4[a]	20,196[a]

[a]Capacity was not reached by 2050. The values given are those for 2050.

TABLE 7.12 STRUCTURAL SCENARIO EFFECTIVENESS SUMMARY

Welland Canal Locks

Structural Scenario	Capacity Year	Tonnage at Capacity (10^3 ST)	Composite Ship Class	Tonnage per Lockage (ST)
Non-Structural to Maximum Utility	1996	88,598	6.2	10,972
1350 by 115 ft Lock	2034	128,693	7.2	17,438
1460 by 145 ft Lock	2046	148,229	7.8	20,134
28 ft Draft	2012	102,558	6.2	12,632
32 ft Draft	2030	122,586	6.1	14,955
Constrained Cargo	1996	87,400	6.2	11,012
1350 by 115 ft Lock at Soo	2050	87,400	6.1	11,093

TABLE 7.13 STRUCTURAL SCENARIO EFFECTIVENESS SUMMARY

St. Lawrence River Locks

Structural Scenario	Capacity Year	Tonnage at Capacity (10^3 ST)	Composite Ship Class	Tonnage per Lockage (ST)
Non-structrual to Maximum Utility	2024	108,597	6.1	11,621
1350 by 115 ft Locks	2048	144,539	7.1	16,899
1460 by 145 ft Locks	Past 2050	148,259[1]	7.7	19,890
28 ft Draft	2034	122,945	6.0	13,074
32 ft Draft	2046	141,885	6.0	15,379
Constrained Cargo 1350 by 115 ft Lock at Soo	Past 2050	95,429[1]	6.0[1]	11,493[1]

[1]Capacity was not reached by 2050. The values given are those for 2050.

The results of Scenario 5 indicate that a second large lock at the Soo would be effective, even if no structural changes were made to the Welland Canal and St. Lawrence River Lock Systems and the Welland Canal went to capacity. Under conditions where the Welland Canal reached capacity in 1996 and no improvements were made, the Soo would reach capacity in 2020. Construction of a new 1350 by 115 foot lock at the Soo will extend capacity well beyond 2050.

8. COST OF CAPACITY EXPANSION ALTERNATIVES

The purpose of this study was to test the sensitivity of the Great Lakes/St. Lawrence Seaway System to the non-structural alternatives for increasing system capacity. The feasibility of implementing the alternatives was only examined in terms of their effects on increasing system wide capacity to the year 2050.

The alternatives tested in this analysis are in the conceptual design stage only. Since it was beyond the scope of this study to prepare designs of these alternatives in any detail, and since accurate cost estimates may only be made from reasonably detailed designs, the cost estimates contained herein must be considered to be rough order of magnitude estimates.

This section of this report contains the estimates of capital and annual operation and maintenance costs for the non-structural expansion measures and the structural scenarios. These cost estimates were based on, and were updated from, the reference literature where possible, however, in some cases such costs were not available, or the published costs were not directly applicable and had to be adjusted. In these cases where cost information could not be used directly, engineering judgement was used to develop reasonable cost estimates. Sources of information have been indicated where applicable.

Table 8.1 gives a summary of the estimated capital costs and the estimated increase in annual operation and maintenance costs of each of the non-structural and structural alternatives.

8.1 Traveling Kevels

The cost of retrofitting traveling kevels on an existing lock was estimated to be approximately $700 per foot of rail in mid-1979 dollars [4]. Updated to January 1981 dollars, this cost is $820 per foot. The inflation factor of 1.17 was obtained using the *Engineering News Record*, "Construction Cost Index" [15] of approximately 2900 in mid-1979 and 3400 for January 1981.

TABLE 8.1 COST ESTIMATES

ALTERNATIVE	SOO LOCKS CAPITAL (10^6 $)	SOO LOCKS O&M (10^3 $/yr)	WELLAND CANAL CAPITAL (10^6 $)	WELLAND CANAL O&M (10^3 $/yr)	ST. LAWRENCE RIVER CAPITAL (10^6 $)	ST. LAWRENCE RIVER O&M (10^3 $/yr)
Non-Structural						
Traveling Kevels	12	720	17	1,040	15	910
Increase Ship Speed	2	200	3.5	350	3	300
Reduce Chamber Time	41	500	98	800	81	700
Traffic Control	1	100	1	100	2	200
Non-Structurals to Maximum Utility	48	820	108	1,140	91	1,110
Scenario 1 - 1350 x 115' Locks	344	421	2,081	0	3,624	0
Scenario 2 - 1460 x 145' Locks	566	1,359	2,456	0	4,631	0
Scenario 3 - 28' Vessel Draft	3,284	482	1,245	0	2,974	0
Scenario 4 - 32' Vessel Draft	11,410	587	1,499	0	4,158	0
Scenario 5 - 1350 x 115' Soo Only	344	421	0	0	0	0

The amount of rail required for a traveling kevel is approximately equal to the length of the guide wall on the lock. It was assumed that rails would be required on both sides of the lock. Traveling kevels were assumed to be placed on all of the locks on the GL/SLS System including the Sabin and Davis Locks. The costs of installing traveling kevels in January 1981 dollars is estimated to be $12,000,000 at the Soo, $17,000,000 at the Welland Canal, and $15,000,000 at the St. Lawrence River.

Annual operation and maintenance costs were estimated at approximately $42 per foot of rail in mid-1979 dollars [14]. Updated to January 1981 dollars by the 1.17 inflation factor, the operating cost is estimated to be $50 per foot of rail. The yearly operation and maintenance costs in January 1981 dollars are then estimated to be $720,000 at the Soo, $1,040,000 at the Welland Canal, and $910,000 at the St. Lawrence River.

8.2 Increase Ship Speed Into Lock

The capital cost associated with allowing increased ship speeds into the locks consists of the costs of installing the safety bumpers and fenders in the locks. The cost of these safety devices is estimated to be approximately $400,000 to $500,000 per lock [16] in January 1981 dollars. The costs of the bumpers and fenders are then estimated to be $2,000,000 for the Soo Locks, $3,500,000 for the Welland Canal, and $3,000,000 for the St. Lawrence River Locks.

No operation and maintenance cost information is available for the safety bumpers and fenders. Annual operation and maintenance costs are assumed to be 10% of the capital expenditure. The annual operation and maintenance costs are therefore estimated to be $200,000 at the Soo, $350,000 at the Welland Canal, and $300,000 at the St. Lawrence River.

8.3 Reduce Chambering Time

The reduce chambering time alternative is made up of two components: reduce dump/fill times and downstream longitudinal hydraulic assistance. Reducing the lock dump/fill times requires replacement of the lock hydraulic system. Hydraulic system costs were estimated in Appendix F of the

1977 draft "Maximum Ship Size Study" [17], based on a report prepared by the St. Lawrence Seaway Authority [18]. The costs were estimated to be approximately $6,200,000 for low lift locks and $9,200,000 for high lift locks. All locks estimated were current St. Lawrence Seaway sized locks.

Updated to January 1981 dollars by use of the "Construction Cost Index" of 2656 in September 1977 and 3400 in January 1981, the hydraulic system costs were estimated to be $8,000,000 for low lift locks and $12,000,000 for high lift locks. Since the Poe Lock is considerably larger than the locks on the St. Lawrence Seaway, the cost for replacing its hydraulic system was assumed to be that of a high lift lock whereas the other Soo Locks were assumed to be low lift locks. The estimated costs for reducing dump/fill time are $36,000,000 at the Soo, $90,000,000 at the Welland Canal, and $74,000,000 at the St. Lawrence River.

The cost of implementing downstream longitudinal hydraulic assistance was estimated to be approximately $1,000,000 per lock for St. Lawrence Seaway sized locks. Costs at the Soo Locks are assumed to be higher because longer ships may be handled through these locks. The cost at each of the Soo Locks is estimated to be $1,200,000. The implementation costs of downstream longitudinal hydraulic assistance are therefore estimated to be $5,000,000 at the Soo, $8,000,000 at the Welland Canal, and $7,000,000 at the St. Lawrence River. The total costs of reducing lock chambering time are then estimated to be $41,000,000 at the Soo, $98,000,000 at the Welland Canal, and $81,000,000 at the St. Lawrence River.

The operation and maintenance costs for the modified lock hydraulic systems will not be any greater than the current operation and maintenance costs for the existing systems. No additional operation and maintenance costs would result from rebuilding the lock hydraulic systems. No costs were available for the operation and maintenance of downstream longitudinal hydraulic assistance systems. Yearly operation and maintenance costs are estimated to be 10% of the implementation costs. The estimated costs are then $500,000 at the Soo, $800,000 at the Welland Canal, and $700,000 at the St. Lawrence River.

8.4 Lock Traffic Control System

This alternative, primarily consisting of closed circuit television and computer controls was estimated to cost approximately $1,000,000 at the Soo Locks, $1,000,000 at the Welland Canal Locks, and $2,000,000 at the St. Lawrence River Locks. Analysis of similar systems showed annual operation and maintenance costs to be approximately 10% of the investment cost [16]. Annual operation and maintenance costs are then estimated to be $100,000 at the Soo, $100,000 at the Welland, and $200,000 at the St. Lawrence River.

8.5 Non-Structural Alternatives to Maximum Utility

This combination of non-structural alternatives consists of traveling kevels, decreased dump/fill times, and a traffic control system. The capital costs for implementing these three alternatives are estimated to be $43,000,000 at the Soo, $108,000,000 at the Welland Canal, and $91,000,000 at the St. Lawrence River. The annual operation and maintenance costs for the combination of the three alternatives are estimated to be $820,000 at the Soo, $1,140,000 at the Welland Canal, and $1,110,000 at the St. Lawrence River.

8.6 Scenario 1 - 1350 by 115 Foot Locks

The costs for building 1350 by 115 foot locks capable of handling 1100 by 105 foot ships (Class 11) were obtained directly from the draft update of the costs from the "Maximum Ship Size Study" [19]. The costs considered were lock costs, channel costs, harbor costs, and bridge and tunnel replacement costs.

The costs for the Soo Locks include, in addition to the new lock, all the corresponding improvement costs for the St. Marys River, St. Clair River-Lake St. Clair-Detroit River, Straits of Mackinac, and 17 major Upper Lakes harbors as listed in Table 8.2. The costs for the Welland Canal include the cost of four new locks and the associated Welland Canal improvements. The costs for the St. Lawrence River include the costs of five new locks and the associated St. Lawrence River improvements.

TABLE 8.2 MAJOR UPPER LAKES HARBORS TO BE IMPROVED

Lake Superior:	Duluth-Superior, MN-WI
	Presque Isle, MI
	Two Harbors, MN
Lake Michigan:	Burns Harbor, IN
	Calumet, IL
	Gary, IN
	Indiana Harbor, IN
	Milwaukee, WI
Lake Huron:	Detroit Harbor, MI
Lake Erie:	Ashtabula, OH
	Buffalo, NY
	Cleveland, OH
	Conneaut, OH
	Lorain, OH
	Sandusky, OH
	Toledo, OH

The following cost items comprise the estimate for the Soo Locks to allow passage of 1100 by 105 foot vessels.

1.	1350 by 115 foot Lock	$ 87,000,000
2.	Major Harbor Dredging	257,000,000
	TOTAL	$ 344,000,000

The following items comprise the cost estimate to reconstruct the Welland Canal for the 1100 by 105 foot vessels.

1.	Four 1350 by 115 foot Locks	$ 738,000,000
2.	Channel Construction	1,343,000,000
	TOTAL	$2,081,000,000

The following items comprise the cost estimate to reconstruct the St. Lawrence River System for 1100 by 105 foot vessels.

1.	Five 1350 by 115 foot Vessels	$ 621,000,000
2.	Channel Dredging	2,894,000,000
3.	Bridges and Tunnels	109,000,000
	TOTAL	$3,624,000,000

The Maximum Ship Size Study [17] determined that the only additional maintenance costs due to modifying the GL/SLS System to handle 1100 by 105 foot ships would be that of maintenance dredging the 17 major harbors that were improved to handle those ships. The annual increased operation and maintenance cost for the Soo Locks is estimated to be $421,000. No increased operation and maintenance costs are expected for the Welland Canal or the St. Lawrence River because of these improvements.

3.7 Scenario 2 - 1460 by 145 Foot Locks

The costs for building 1460 by 145 foot locks which are capable of handling 1200 by 130 foot (Class 12) vessels were obtained directly from the draft report of the updated costs

for the Maximum Ship Size Study [19]. The costs considered were lock costs, channel costs, harbor costs, and bridge and tunnel replacement costs.

The cost estimate for the Soo Locks includes the costs of the new lock, channel dredging for the St. Marys River, the Straits of Mackinac, St. Clair River-Lake, St. Clair-Detroit River, and seventeen major Upper Lake harbors. The cost estimate for the Welland Canal includes the cost of four new locks and channel construction. The cost estimate for the St. Lawrence River includes the cost of five new locks and St. Lawrence River modifications.

The cost estimate for the Soo Locks is comprised of the following:

1460 by 145 foot Lock	$ 100,000,000
Channel Dredging	2,739,000,000
Harbor Dredging	527,000,000
TOTAL	$3,366,000,000

The cost estimate for the Welland Canal includes the following:

Four 1460 by 145 foot Locks	$ 836,000,000
Channel Dredging	1,620,000,000
TOTAL	$2,456,000,000

The cost estimate for the St. Lawrence River includes the following:

Five 1460 by 145 foot Locks	$ 706,000,000
Channel Dredging	3,790,000,000
Bridges and Tunnels	135,000,000
TOTAL	$4,631,000,000

It was determined in the "Maximum Ship Size Study" [17] that the only additional maintenance cost derived from modifying the GL/SLS system to handle 1200 by 130 foot ships would be that

of maintaining the required dimensions in the 17 harbors which were improved. The annual increase in operation and maintenance costs for the Soo Locks is $1,359,000. No increased operation and maintenance costs are expected for the Welland Canal or the St. Lawrence River.

8.8 Scenario 3 - 28 Foot Draft

The "Maximum Ship Size Study" [17] did not analyze the costs of deepening the GL/SLS System without increasing the maximum ship size at the same time. The cost estimates in the updated "Maximum Ship Size Study" [19] must therefore be adjusted to develop the cost estimate for this scenario. In most cases the 940 by 105 foot estimate was used, scaled down by the significant ship dimension.

The cost for deepening the existing locks to 28 feet was estimated to be approximately twice the cost differential between constructing a new lock with 28 foot draft and constructing one with 25.5 foot draft. For the Poe Lock the 1100 by 105 foot ship estimate was used. The Sabin and Davis Locks were not deepened. For the remaining locks the 940 by 105 foot estimate was used, scaled down by 80%. The costs of lock deepening are estimated to be $29,000,000 at the Soo, $110,000,000 at the Welland Canal, and $79,000,000 at the St. Lawrence River.

The channel dreding estimates in the Maximum Ship Size Study are only functions of ship draft and beam. Therefore, estimates for the St. Lawrence River and Welland Canal channels may be proportioned from 105 feet to 80 feet, and the 105 foot estimate may be applied directly for the Upper Lakes channels. The channel dredging costs are $2,066,000,000 at the Soo, $1,135,000,000 at the Welland, and $2,858,000,000 at the St. Lawrence River. A cost of $436,000,000 for compensating works must also be added to the Soo estimate.

Tunnel costs are only draft dependent and therefore may be taken directly. Tunnel modifications are only required in the St. Lawrence River at a cost of $37,000,000.

Harbor dredging is mainly a function of ship length and draft. Therefore, the Soo costs for dredging the 17 major Upper Lake harbors was obtained by scaling the 1100 by 105 foot estimate to 1000 by 105 feet. The harbor dreding cost for the Soo is estimated to be $753,000,000.

The total costs for increasing system draft to 28 feet are then estimated to be $3,284,000,000 at the Soo, $1,245,000,000 at the Welland, and $2,974,000,000 at the St. Lawrence River.

The increase in annual operation and maintenance expenditures due to the 28 foot draft is equal to the increased maintenance dredging cost of the harbors. This cost, obtained from the updated Maximum Ship Size Study and scaled down to 1000 by 105 foot ships, is estimated to be $482,000, applicable to the Soo Locks.

8.9 Scenario 4 - 32 Foot Draft

As was the case with Scenario 3 where system draft was increased to 28 feet, costs were not directly available from the Maximum Ship Size Study for deepening the GL/SLS System to 32 feet without also increasing the maximum ship size. The cost estimates in the cost update to the Maximum Ship Size Study were therefore adjusted to develop the cost estimate for this scenario. In most cases the estimate was made assuming a 940 by 105 foot maximum sized ship, scaled down by the significant ship dimension.

The cost for deepening the existing locks to 32 feet was estimated to be approximately twice the difference between the cost of constructing new 32 foot draft locks and the cost of constructing new 25.5 foot draft locks. For the Poe Lock the 1100 by 105 foot ship estimate was used. The Sabin and Davis Locks were not deepened since they mainly carry ballasted traffic. For the remaining locks the 940 by 105 foot cost estimate was used, scaled down to a 730 by 80 foot ship size by using 80% of the estimate. The costs of deepening the locks to 32 feet are then estimated to be $55,000,000 at the Soo, $117,000,000 at the Welland Canal, and $149,000,000 at the St. Lawrence River.

The Maximum Ship Size Study stated that the significant dimensions for channel dredging are ship draft and beam. The cost estimates for the St. Lawrence River and Welland Canal may be direcly proportioned from 105 to 80 feet. The 105 foot beam estimate may be used directly for the Upper Lakes channels. The estimated channel dredging costs are $9,455,000,000 for the Soo, $1,322,000,000 for the Welland Canal, and $3,966,000,000 for the St. Lawrence River. A cost of $547,000,000 must be added to the Soo cost estimate for flow compensating structures.

Harbor dredging is primarily a function of ship draft and length. The costs for dredging the 17 major Upper Lakes harbors were obtained by scaling the estimate for the 1100 by 105 foot ship down to a 1000 by 105 foot ship. The estimated cost for harbor dredging which is applied to the Soo is estimated to be $1,355,000,000.

Tunnel costs are strictly draft dependent and therefore estimates may be made directly from the updated Maximum Ship Size Study cost estimates. Tunnel modifications are only required at the St. Lawrence River where the cost is estimated to be $43,000,000.

The total construction costs for increasing the draft of the GL/SLS System to 32 feet are therefore estimated to be $11,410,000,000 at the Soo, $1,499,000,000 at the Welland Canal, and $4,158,000,000 at the St. Lawrence River.

The increase in operation and maintenance costs due to increasing system-wide draft to 32 feet is estimated to be the increased cost of harbor maintenance dredging. This estimate was obtained from the 1100 by 105 foot ship estimate in the updated Maximum Ship Size Study, and scaled down to the 1000 by 105 foot ship size. The increased operation and maintenance cost, which is applied only to the Soo Locks, is estimated to be $587,000 per year.

8.10 Scenario 5 - Constrained Cargo Flows

The only capital costs which must be expended in this alternative are those of constructing a new 1350 by 115 foot lock at the Soo, capable of handling 1100 by 105 foot ships. This estimate was developed previously as part of Scenario 1. The costs considered were lock costs, channel costs, and harbor costs.

The Soo Lock costs for constructing a 1350 by 115 foot lock include in addition to the cost of the new lock, the costs for modifying the St. Marys River, St. Clair River-Lake, St. Clair-Detroit River, the Straits of Mackinac, and 17 major Upper Lakes harbors, as listed in Table 8.2, to allow passage of 1100 by 105 foot ships. The following cost items comprise the cost estimate for the Soo Locks:

1350 by 115 foot Lock	\$ 87,000,000
Major Harbor Dredging	257,000,000
TOTAL	\$344,000,000

The total construction cost estimate for Scenario 5 is therefore \$344,000,000.

The annual operation and maintenance cost due to a 1350 by 115 foot lock at the Soo and access for 1100 by 105 foot ships in the Upper Lakes harbors and channels is equal to the increased maintenance dreding cost of the Upper Lakes harbors. The annual operation and maintenance cost is estimated to be \$421,000 per year.

9. ANALYSIS OF CAPACITY EXPANSION SENSITIVITY RESULTS

9.1 Summary of Capacity Analyses

Tables 9.1 through 9.9 summarize the results of the lock capacity expansion alternatives sensitivity and feasibility analysis. Each table summarizes a set of runs commencing at the base year of 1978. The non-structural alternative analysis summaries, Tables 9.1 through 9.4, give the base case, or existing system, capacity conditions and the individual non-structural improvement alternative capacity conditions. The structural and alternative analysis summaries, Tables 9.5 through 9.9, give the base case capacity conditions, the non-structural alternatives combined to maximum utility capacity conditions, and the structural alternative capacity conditions, or the year 2050 conditions if capacity is not reached by then.

The following information is contained in each of the summary tables:

1. Capacity Year: The year in which capacity, defined as an average lock utilization of 90% for May through November, is reached. If capacity is not reached by 2050, "past 2050" is specified.

2. Tonnage at Capacity: The total amount of cargo processed through the lock system in the capacity year. If capacity is not reached by 2050, the 2050 cargo tonnage is given.

3. Delay Time: The total number of ship waiting hours at the constraining lock during the capacity year. This number is obtained by summing over the year for each direction, the average vessel waiting time at the constraining lock for each monthly period multiplied by the number of transits during that monthly period. If capacity is not reached by 2050, the 2050 delay times are given.

4. Composite Ship Classes: The weighted mean ship class, by commodity, for the fleet utilizing the lock system. The method of obtaining these numbers is given in Section 5.4.1. If capacity is not reached by 2050, the 2050 composite ship classes are given.

TABLE 9.1 RESULTS OF LOCK CAPACITY ANALYSIS

Non-Structural Alternative No. 1 - Traveling Kevels

LOCK	CAPACITY YEAR	TONNAGE @ CAPACITY 100 ST	DELAY[1] TIME hr	COMPOSITE SHIP CLASSES[2] ORE	COAL	STONE	GRAIN	O.BULK	G.CARGO	ACTION TAKEN	CAPITAL[3] COST 10^6\$	O&M[3,4] COST 10^3\$/yr
Soo	2006	173,739	21,710d 3,284u	8.3	7.7	6.1	6.6	5.3	5.7	Traveling Kevels[11]	12	720
Soo	2014	189,501	20,010d 4,270u	8.5	7.8	6.2	6.7	5.2	5.7	--	--	--
Well	1981	75,198	20,052d 29,260u	6.1	6.0	7.0	6.2	5.6	5.6	Traveling Kevels[11]	17	1,040
Well	1985	80,738	17,140d 26,027u	6.3	6.3	7.0	6.3	5.6	5.6	--	--	--
SLR	2006	92,526	30,508d 35,696u	6.7	6.8	7.0	6.5	5.5	5.6	Traveling Kevels[11]	15	910
SLR	2016	100,534	28,323d 32,329u	6.7	6.7	7.0	6.6	5.5	5.6	--	--	--

TABLE 9.2 RESULTS OF LOCK CAPACITY ANALYSIS

Non-Structural Alternative No. 2 - Increase Ship Speed Into Lock

LOCK	CAPACITY YEAR	TONNAGE @ CAPACITY 100 ST	DELAY[1] TIME hr	COMPOSITE SHIP CLASSES[2] ORE	COAL	STONE	GRAIN	O.BULK	G.CARGO	ACTION TAKEN	CAPITAL[3] COST 10^6\$	O&M[3,4] COST 10^3\$/yr
Soo	2006	173,739	27,310d 3,284u	8.3	7.7	6.1	6.6	5.3	5.7	Increase Ship Speed[12]	2	200
Soo	2008	177,988	21,356d 3,413u	8.3	718	6.1	6.6	5.3	5.7	--	--	--
Well	1981	75,198	20,052d 29,260u	6.1	6.0	7.0	6.2	5.6	5.6	Increase Ship Speed[12]	3.5	350
Well	1984	78,921	17,603d 28,776u	6.2	6.2	7.0	6.3	5.6	5.6	--	--	--
SLR	2006	92,526	30,508d 35,696u	6.7	6.8	7.0	6.5	5.5	5.6	Increase Ship Speed[12]	3.0	300
SLR	2010	96,198	32,125d 34,272u	6.7	6.7	7.0	6.6	5.5	5.6	--	--	--

TABLE 9.3 RESULTS OF LOCK CAPACITY ANALYSIS

Non-Structural Alternative No. 3 - Reduce Chambering Time

LOCK	CAPACITY YEAR	TONNAGE @ CAPACITY 100 ST	DELAY[1] TIME hr	COMPOSITE SHIP CLASSES[2] ORE	COAL	STONE	GRAIN	O.BULK	G.CARGO	ACTION TAKEN	CAPITAL[3] COST $10^6$$	O&M[3,4] COST $10^3$$/yr
Soo	2006	173,739	21,710d 3,284u	8.3	7.7	6.1	6.6	5.3	5.7	Reduce Chamber Time[13]	41	500
Soo	2010	182,250	20,794d 4,226u	8.4	7.8	6.2	6.6	5.3	5.7	--	--	--
Well	1981	75,198	20,052d 29,260u	6.1	6.0	7.0	6.2	5.6	5.6	Reduce Chamber Time[13]	98	800
Well	1983	78,839	17,988d 25,225u	6.2	6.2	7.0	6.3	5.6	5.6	--	--	--
SLR	2006	92,526	30,508d 35,696u	6.7	6.8	7.0	6.5	5.5	5.6	Reduce Chamber Time[13]	81	800
SLR	2010	96,535	19,913d 34,596u	6.7	6.7	7.0	6.6	5.6	5.6	--	--	--

TABLE 9.4 RESULTS OF LOCK CAPACITY ANALYSIS

Non-Structural Alternative No. 4 - Local Traffic Control System

LOCK	CAPACITY YEAR	TONNAGE @ CAPACITY 100 ST	DELAY[1] TIME hr	COMPOSITE SHIP CLASSES[2] ORE	COAL	STONE	GRAIN	O.BULK	G.CARGO	ACTION TAKEN	CAPITAL[3] COST 10^6\$	O&M[3,4] COST 10^3\$/yr
Soo	2006	173,739	21,710d 3,284u	8.3	7.7	6.1	6.6	5.3	5.7	Traffic Control	1	100
Soo	2010	182,250	21,300d 3,754u	8.4	7.8	6.2	6.6	5.3	5.7	--	--	--
Well	1981	75,198	20,052d 29,260u	6.1	6.0	7.0	6.2	5.6	5.6	Traffic Control	1	100
Well	1983	78,735	20,027d 29,296u	6.2	6.2	7.0	6.3	5.6	5.7	--	--	--
SLR	2006	92,526	30,508d 35,696u	6.7	6.8	7.0	6.5	5.5	5.6	Traffic Control	2	200
SLR	2012	97,789	32,042d 36,007u	6.7	6.7	7.0	6.6	5.5	5.6	--	--	--

TABLE 9.5 RESULTS OF LOCK CAPACITY ANALYSIS

Scenario No. 1 - Non-Structural to Maximum Utility, 1350 x 115' Locks Added at Constrained Sites to Pass Unconstrained Traffic

LOCK	CAPACITY YEAR	TONNAGE @ CAPACITY 100 ST	DELAY[1] TIME hr	COMPOSITE SHIP CLASSES[2] ORE	COAL	STONE	GRAIN	O.BULK	G.CARGO	ACTION TAKEN	CAPITAL[3] COST 10^6\$	O&M[3,4] COST 10^3\$/yr
Soo	2006	173,739	21,710d 3,284u	8.3	7.7	6.1	6.6	5.3	5.7	N/S to max utility[5]	48	820
Soo	2018	196,766	20,386d 5,147u	8.6	7.9	6.2	6.7	5.2	5.7	1350 x 115 lock[6]	344	421
Soo	2050	272,245	21,224d 7,169u	916	9.3	6.3	8.6	5.0	6.8	--	--	--
Well	1981	75,198	20,052d 29,260u	6.1	6.0	7.0	6.2	5.6	5.6	N/S to max utility[5]	108	1,140
Well	1996	88,598	17,432d 25,220u	6.8	6.8	7.0	6.5	5.6	5.7	1350 x 115 locks[6]	2,081	0
Well	2034	128,693	18,250d 28,869u	9.2	8.4	7.0	9.1	5.6	6.6	--	--	--
SLR	2006	92,526	30,508d 35,696u	6.7	6.8	7.0	6.5	5.5	5.6	N/S to max utility[5]	91	1,110
SLR	2024	108,597	29,994d 31,913u	6.7	6.7	7.0	6.6	5.5	5.6	1350 x 115 locks[6]	3,624	0
SLR	2043	144,539	28,043d 29,684u	9.3	8.7	6.5	9.3	5.5	6.6	--	--	--

TABLE 9.6 RESULTS OF LOCK CAPACITY ANALYSIS

Scenario No. 2 - Non-Structural to Maximum Utility, 1460 x 145' Locks Added at Constrained Sites to Pass Unconstrained Traffic

LOCK	CAPACITY YEAR	TONNAGE @ CAPACITY 100 ST	DELAY[1] TIME hr	COMPOSITE SHIP CLASSES[2] ORE	COAL	STONE	GRAIN	O.BULK	G.CARGO	ACTION TAKEN	CAPITAL[3] COST 10^6\$	O&M[3 4] COST 10^3\$/yr
Soo	2006	173,739	21,710d 3,284u	8.3	7.7	6.1	6.6	5.3	5.7	N/S to max utility[5]	48	820
Soo	2018	196,766	20,386d 5,147u	816	7.9	6.2	6.7	5.2	5.7	1460 x 145 lock[7]	3,366	1,359
Soo	past 2050"	272,247 @2050	14,940d 9,726u	10.2	9.5	6.2	9.8	4.9	6.8	--	--	--
Well	1981	75,198	20,052d 29,260u	6.1	6.0	7.0	6.2	5.6	5.6	N/S to max utility[5]	108	1,140
Well	1996	88,598	17,432d 25,220u	6.8	6.8	7.0	6.5	5.6	5.7	1406 x 145 locks[7]	2,456	0
Well	2046	148,299	18,471d 26,520u	9.8	9.0	7.0	9.8	6.7	7.0	--	--	--
SLR	2006	92,526	30,508d 35,696u	6.7	6.8	7.0	6.5	5.5	5.6	N/S to max utility[5]	91	1,110
SLR	2024	108,597	29,994d 31,913u	6.7	6.7	7.0	6.6	5.5	5.6	1460 x 145 locks[7]	4,631	0
SLR	past 2050"	148,259 @ 2050	7,405d 7,505u	918	9.2	6.5	9.8	6.7	7.0	--	--	--

TABLE 9.7 RESULTS OF LOCK CAPACITY ANALYSIS

Scenario No. 3 - Non-Structural to Maximum Utility, Channel Deepening to 30' System Depth, 28' Vessel Draft, Unconstrained Traffic

LOCK	CAPAICTY YEAR	TONNAGE @ CAPACITY 1000 ST	DELAY[1] TIME hr	COMPOSITE SHIP CLASSES[2] ORE	COAL	STONE	GRAIN	O.BULK	G.CARGO	ACTION TAKEN	CAPITAL[3] COST 10^6\$	O&M[3,4] COST 10^3\$/yr
Soo	2006	173,739	21,710d 3,284u	8.3	7.7	6.1	6.6	5.3	5.7	N/S to max utility[5]	48	820
Soo	2018	196,766	20,386d 5,147u	8.6	7.9	6.2	6.7	5.2	5.7	28 foot draft	3,284	482
Soo	2026	213,734	21,988d 5,567u	8.8	7.9	6.2	6.6	5.1	5.7	--	--	--
Well	1981	75,198	20,052d 29,260u	6.1	6.0	7.0	6.2	5.6	5.6	N/S to max utility[5]	108	1,140
Well	1996	88,598	17,432d 25,220u	6.8	6.8	7.0	6.5	5.6	5.7	28 foot draft	1,245	0
Well	2012	102,558	17,291d 25,390u	6.8	6.9	7.0	6.6	5.6	5.6	--	--	--
SLR	2006	92,526	30,508d 35,696u	6.7	6.8	7.0	6.5	5.5	5.6	N/S to max utility[5]	91	1,110
SLR	2024	108,597	29,994d 31,913u	6.7	6.7	7.0	6.6	5.5	5.6	28 foot draft	2,974	0
SLR	2034	122,945	26,527d 29,344u	6.7	6.7	7.0	6.6	5.5	5.6	--	--	--

TABLE 9.8 RESULTS OF LOCK CAPACITY ANALYSIS

Scenario No. 4 - Non-Structural to Maximum Utility, Channel Deepening to 34' System Depth, 32' Vessel Draft, Unconstrained Traffic

LOCK	CAPACITY YEAR	TONNAGE @ CAPACITY 1000 ST	DELAY[1] TIME	COMPOSITE SHIP CLASSES[2] ORE	COAL	STONE	GRAIN	O.BULK	G.CARGO	ACTION TAKEN	CAPITAL[3] COST 10^6\$	O&M[3,4] COST 10^3\$/yr.
Soo	2006	173,739	21,710d 3,284u	8.3	7.7	6.1	6.6	5.3	5.7	N/S to max utility[5]	48	820
Soo	2018	196,766	20,386d 5,147u	8.6	7.9	6.2	6.7	5.2	5.7	32 foot draft	11,410	587
Soo	2038	241,652	20,115d 5,671u	8.8	8.0	6.3	6.6	5.0	5.7	--	--	--
Well	1981	75,198	20,052d 29,260u	6.1	6.0	7.0	6.2	5.6	5.6	N/S to max utility[5]	108	1,140
Well	1996	88,598	17,432d 25,220u	6.8	6.8	7.0	6.5	5.6	5.7	32 foot draft	1,499	0
Well	2030	122,586	17,778d 28,538u	6.7	6.8	7.0	6.6	5.5	5.6	--	--	--
SLR	2006	92,526	30,508d 35,696u	6.7	6.8	7.0	6.5	5.5	5.6	N/S to max utility[5]	91	1,110
SLR	2024	108,597	29,994d 31,913u	6.7	6.7	7.0	6.6	5.5	5.6	32 foot draft	4,158	0
SLR	2046	141,885	27,084d 30,463u	6.6	6.7	7.0	6.6	5.5	5.6	--	--	--

TABLE 9.9 RESULTS OF LOCK CAPACITY ANALYSIS

Scenario No. 5 - *Non-Structural to Maximum Utility, Then Constrained Cargo Flow due to Welland, 1350 x 115' Lock at Soo*

LOCK	CAPACITY YEAR	TONNAGE @ CAPACITY 1000 ST	DELAY[1] TIME	COMPOSITE SHIP CLASSES[2] ORE	COAL	STONE	GRAIN	O.BULK	G.CARGO	ACTION TAKEN	CAPITAL[3] COST 10^6\$	O&M[3,4] COST 10^3\$/yr
Soo	2008	173,483	20,854d 3,975u	8.3	7.8	6.2	6.6	5.3	5.7	N/S to max utility[5]	48	820
Soo	2020	191,944	22,108d 5,329u	8.6	7.9	6.3	6.7	5.2	5.7	1350 x 115 lock[6]	344	421
Soo	past 2050[8]	248,051 @ 2050	3,134d 2,204u	9.4	8.8	6.3	6.7	5.0	5.7	--	--	--
Well	1981	75,185	20,052d 29,260u	6.1	6.1	7.0	6.2	5.6	5.6	N/S to max utility[5]	108	1,140
Well	past 2050[8]	87,402	10,951d 13,829u	6.6	6.7	7.0	6.6	5.5	5.6	--	--	--
SLR	2040	92,582	30,532d 35,557u	6.6	6.8	7.0	6.6	5.5	5.6	N/S to max utility[5]	91	1,110
SLR	past 2050[8]	95,429 @ 2050	5,594d 5,740u	6.6	6.8	7.0	6.6	5.5	5.6	--	--	--

NOTES TO TABLES 9.1 THROUGH 9.9

1. Delay time is the cumulative waiting time during the capacity year for the constraining lock.

2. Class 6 ships are oceangoing. Class 5 ships are laker classes 5 and 6.

3. Soo Locks costs include the capital or O&M costs of the Soo Locks, the St. Marys River, the St. Clair River, the Detroit River, the Straits of Mackinac, and 17 major Upper Lakes harbors. Welland Canal costs include the capital or O&M costs for the Welland Locks and Canal. St. Lawrence River Locks costs include the capital or O&M costs for the St. Lawrence River and the locks.

4. Operation and maintenance costs given are the additional costs due to the improvements. Zero O&M cost indicates no increase over the no-project level due to the project.

5. N/S to max utility: Non-structural improvements taken to maximum utility consisting of traveling kevels, reduced dump/fill times, and lock traffic control systems. Locking times are reduced 13% in total at each lock system.

6. The 1350 ft x 115 ft lock is capable of passing a 1100 x 105 ft ship (Class 11).

7. The 1460 ft x 145 ft lock is capable of passing a 1200 x 130 ft ship (Class 12).

8. Tonnage, Delay Time, and Composite Ship Class are at 2050.

9. Classes 8 and 9 for the St. Lawrence River and Welland Canal include ocean-going ships longer than 700 feet as well as lakers.

10. Cargos are constrained by the Welland Canal reaching capacity at 1996.

11. Traveling kevels reduce locking times 7.5% at all locks by reducing lock entrance times.

12. Increase ship speed into lock by providing safety bumpers and fenders. Locking time reduced 2.5% at the Soo and St. Lawrence River Locks, and 5.0% at the Welland Canal Locks.

13. Lock Chambering Time decreased by reducing dump/fill and by providing downstream longitudinal assistance. Locking times reduced 5.5% downbound and 1.0% upbound at the Soo and St. Lawrence River Locks, and 5.0% downbound and 2.5% upbound at the Welland Canal Locks.

14. Lock approach times reduced by implementing a local traffic control system. Locking times reduced upbound and downbound 4.5% at the Soo and St. Lawrence River Locks, and 3.0% at the Welland Canal Locks.

15. Vessel draft is 25.5' unless otherwise specified.

5. Action Taken: The capacity expansion alternative that is implemented to relieve the capacity condition.

6. Capital Cost: The estimated initial cost of implementing the capacity expansion measure listed in "Action Taken".

7. O&M Cost: The estimated additional annual costs that will be incurred as a result of implementing the expansion measure listed in "Action Taken". A zero under 'O&M Cost' indicates that the operation and maintenance costs will not increase above the existing levels as a result of implementing the alternatives.

9.2 Capacity Increase/Cost Analysis

The results of this study are intended to provide insight into the effects of expanding the capacity of the GL/SLS System. This study is a sensitivity and feasibility analysis intended to determine the relative merits of several means of achieving capacity expansion. The output of this study will be the determination of any viable capacity expansion measures which show promise toward relieving the capacity conditions at the locks and which deserve further analysis. Before a decision is made concerning the implementation of any of these alternatives, further testing in more sophisticated and more detailed models which closely simulate the finer details of the locking operation at each of the three lock systems, and design work to develop more accurate and detailed cost estimates, will be required.

While the alternatives investigated will be analyzed in terms of NED Benefits, as a preliminary means of determining the relative value of the capacity expansion measures tested in this sensitivity analysis, the increase in tonnage processed per dollar of capital cost can be compared for each of the alternatives. This means of evaluation is not sufficient to make final decisions on these alternatives, but may be used to give a preliminary relative ranking. Table 9.10 gives the increased tonnage per dollar of investment cost of each of the alternatives at each of the lock systems.

Examining the results shown on Table 9.10, the nonstructural alternatives appear to give much better improvement

TABLE 9.10 CAPACITY INCREASE PER UNIT OF CAPITAL COST

ALTERNATIVE	SOO			WELLAND CANAL			ST. LAWRENCE RIVER		
	CAPACITY INCREASE (10^6 ST)	CAPITAL COST (10^6 \$)	INCREASE PER COST (ST/\$)	CAPACITY INCREASE (10^6 ST)	CAPITAL COST (10^6 \$)	INCREASE PER COST (ST/\$)	CAPACITY INCREASE (10^6 ST)	CAPITAL COST (10^6 \$)	INCREASE PER COST (ST/\$)
Traveling Kevels	15.762	12	1.31	5.540	17	0.326	8.008	15	0.534
Increase Ship Speed Into Lock	4.249	2	2.12	3.723	3.5	1.06	3.627	3.0	1.22
Reduce Chambering Time	8.511	41	0.208	3.641	98	0.031	4.009	81	0.049
Local Traffic Control System	8.511	1	8.51	3.537	1	3.54	5.263	2	2.63
Non-Structural to Maximum Utility	23.027	48	0.480	13.400	108	0.124	16.071	91	0.177
1350 by 115 foot Locks at All Sites	75.479	344	0.219	40.095	2,081	0.019	35.942	3,624	0.010
1460 by 145 foot Locks at All Sites	>75.481[1]	3,366	>0.022[1]	59.701	2,456	0.024	>39.662[1]	4,631	0.009[1]
28 ft Vessel Draft	16.698	3,284	0.005	13.960	1,245	0.011	14.348	2,974	0.005
32 ft Vessel Draft	44.886	11,410	0.004	33.988	1,499	0.023	33.288	4,158	0.008
1350 by 115 ft Locks at Soo, Constrained Cargo Forecasts	>56.107[1]	344	0.163[1]	--	--	--	--	--	--

NOTES: 1. Capacity was not reached before 2050. The capacity increase given is the 2050 tonnage. The increase per unit cost given is based on the 2050 tonnage. The actual capacity increase and increase per unit cost figures for these alternatives will therefore be greater than the numbers shown.

per unit of investment than do the structural alternatives. The non-structural alternatives are relatively low cost means of relieving lock capacity conditions over the short term. Structural alternatives, on the other hand, are high cost expansion measures, however, they provide longer term relief in alleviating capacity conditions at the locks. Therefore, in performing long range planning for a lock system, structural and non-structural alternatives must be compared separately. The non-structural alternatives could be used to alleviate immediate capacity conditions, while the structural alternatives should be considered for providing larger capacity gains over longer periods of time.

Based on the increased tonnage per unit cost of implementation, the local traffic control system appears to be the most favorable non-structural alternative at all three lock systems. This is followed by increasing the ship speed into the lock, installing traveling kevels, and lastly, reducing the chambering time.

For the structural alternatives, the 1350 x 115 foot lock appears to be most favorable at the Soo and the St. Lawrence River Locks. The 1460 by 145 foot lock appears to be most favorable at the Welland, and is very close to being the most favorable alternative at the St. Lawrence River. Overall, the 1350 by 115 foot lock is probably the best alternative because there is only a small difference in tonnage per unit cost between the two lock size alternatives at the Welland Canal. The 1460 by 145 foot lock would rank second, followed by 32 foot draft and, finally, 28 foot draft.

Scenario 5, a 1350 by 115 foot lock at the Soo with the Welland Canal at capacity and limiting tonnages, cannot be compared with the other structural alternatives because cargo demand is different for this scenario.

To develop a more accurate ranking, other factors such as operating cost, costs due to waiting at a lock, and the cost of not being able to pass the unconstrained cargo forecasts due to the existence of a capacity condition must be taken into account. Such a detailed analysis is another task of this study which will result in a ranking of the non-structural and structural alternatives in terms of NED Benefits.

10. CONCLUSIONS

The results of any capacity expansion sensitivity and feasibility analysis must be interpreted in terms of the assumptions made for the input parameters. The most significant input parameters for this study include the cargo projections, the locking times, and the changes in locking times associated with each capacity expansion alternative, and the fleet mix and the changes in the fleet mix with time and due to the capacity expansion alternatives. While the input assumptions used in this study were based upon the best information available at the time of the study, it is recognized that differences of opinion exist in some areas, and better assumptions may be possible in the future as more data becomes available or as further analysis is completed. Recognizing this, the following conclusions are drawn from this sensitivity and feasibility analysis of GL/SLS System capacity expansion alternatives:

1. The GL/SLS Lock Capacity Model has been modified for use in analyzing the sensitivity of the System to a broad range of non-structural and structural alternatives for increasing System capacity. The model is especially applicable to feasibility and sensitivity analyses since a large number of runs can be made relatively quickly and at relatively low cost.

2. Existing Conditions

- If the existing high water levels remain, allowing 27 foot draft at the Soo and 26 foot draft in the St. Lawrence Seaway, capacity will be reached in 1984 at the Welland Canal, 2010 at the Soo, and 2014 at the St. Lawrence River.

- If the current high water levels recede to low water datum, resulting in a 25.5 foot system-wide ship draft, capacity will be reached in 1981 at the Welland Canal, 2006 at the Soo, and 2006 at the St. Lawrence River.

3. Non-Structural Alternatives

- Non-structural alternatives provide short term capacity relief at relatively low cost, without requiring major lock or channel construction.

- The most effective individual non-structural alternative tested is traveling kevels which postponed lock capacity until 1985 at the Welland Canal, 2014 at the Soo, and 2016 at the St. Lawrence River.

- Non-structural alternatives can be combined to provide greater capacity increases. Non-structural alternatives considered in this study combined to maximum utility, consisting of installing traveling kevels, reducing dump/fill times, and installing local traffic control systems, provide the greatest non-structural capacity increases in this study. Capacity is delayed until 1996 at the Welland Canal, 2018 at the Soo, and 2024 at the St. Lawrence River, based on an allowable ship draft of 25.5 feet.

4. Structural Scenarios

- The structural scenarios provide longer term capacity expansion but at much greater cost than the non-structural expansion alternatives. Structural expansion entails lock replacement and/or significant channel dredging.

- The 2050 unconstrained cargo forecasts cannot be passed through any of the GL/SLS Lock Systems by constructing 1350 by 115 foot locks capable of handling 1100 by 105 foot (Class 11) vessels at drafts of 25.5 feet. With these locks implemented, capacity is reached in 2034 at the Welland Canal, 2048 at the St. Lawrence River, and 2050 at the Soo.

- The 2050 unconstrained cargo forecasts can be passed through the Soo and St. Lawrence River Locks at 25.5 foot draft by constructing 1460 by 145 foot locks which are capable of handling 1200 by 130 foot (Class 12) ships. The 2050 cargo cannot be passed through the Welland Canal by constructing 1460 by 145 foot locks without increasing draft beyond 25.5 feet. Capacity is reached at the Welland Canal with 1460 by 145 foot locks in 2046 at a 25.5 foot draft.

- Increased ship draft without increased lock size does not provide as much capacity increase as is gained from increased lock size. With existing

lock sizes and 28 foot system-wide draft, capacity is reached in 2012 at the Welland Canal, 2026 at the Soo, and 2034 at the St. Lawrence River. With existing lock sizes and 32 foot system-wide draft, capacity is reached in 2030 at the Welland Canal, 2038 at the Soo, and 2046 at the St. Lawrence River.

- Construction of a new 1350 by 115 foot lock at the Soo would provide significant capacity increase even if no changes were made to the St. Lawrence Seaway Lock Systems beyond the non-structural modifications. With cargo flows constrained due to a capacity condition at the Welland Canal, capacity would be reached in 2020 at the Soo after the installation of the non-structural alternatives combined to maximum utility. Construction of a new 1350 by 115 foot lock then postpones capacity to beyond 2050.

- The Welland Canal cannot pass the 2050 unconstrained cargo flow in any of the scenarios tested. A combination of increased lock size and increased draft, or a different type of scenario such as a parallel lock system will be required at the Welland Canal to pass the 2050 unconstrained cargos.

11. RECOMMENDATIONS

Based on the results of the capacity expansion sensitivity and feasibility analysis presented in this report and the knowledge gained during the study, it is recommended that consideration be given to using the GL/SLS Lock Capacity Model for further analysis of structural and non-structural capacity expansion alternatives as follows:

1. Run additional structural scenarios to gain further insight into the increases in capacity that structural improvements can yield. This is particularly necessary at the Welland Canal where capacity was reached prior to 2050 in all of the scenarios tested in this study. Additional scenarios that might allow the Welland Canal to pass the projected 2050 unconstrained cargos are:

   a. 1460 by 145 foot locks with 28 foot draft at all sites.

   b. 1350 by 115 foot locks with 32 foot draft at all sites.

   c. 1350 by 115 foot locks with 28 foot draft at all sites.

   d. 1350 by 115 foot locks at all sites with a duplicate (parallel) system at the Welland Canal, all at 25.5 foot draft.

   e. 1350 by 115 foot locks at all sites with a duplicate (parallel) system at the Welland Canal, all at 28 foot draft.

The MacArthur Lock was very much under-utilized when the 1460 by 145 foot lock was constructed in place of the Sabin and Davis Locks at the Soo because most of the ships were then too large to fit through the MacArthur. Further expansion scenarios worthy of consideration at the Soo then include:

   f. Build a new MacArthur Lock capable of handling Class 10 ships when the 1460 by 145 foot locks are constructed, maintaining a system-wide draft of 25.5 feet.

g. Build a new MacArthur Lock capable of handling Class 10 ships when the 1460 by 145 foot locks are constructed, with a system-wide draft of 28 feet.

2. Test non-structural alternatives which have effects other than decreasing locking times in order to determine their effectiveness on increasing capacity. Two possible non-structural alternatives of this type are:

a. Lockage Fee. Replacing the current toll system which is based on tonnage by a set fee per lockage. The economic incentives form this alternative would be towards reducing ballasted transits and increasing the use of larger ships which results in an increase in lock capacity.

b. Congestion Toll. Such a toll assesses the user for the social marginal cost due to the delay at the lock in addition to the private marginal cost which he already realizes. The congestion toll has the effect of increasing system efficiency and eliminating the marginal user of the lock.

3. Additional scenarios for increasing system capacity could be run using 10, 11, or 12 month navigation seasons. As further alternatives, the season could be extended in the Upper Lakes only, or in the Upper Lakes for one period of time, and the St. Lawrence River and Welland Canal for a different period of time.

4. A more comprehensive non-structural improvement sensitivity analysis could be run which would give further insight into, and a better understanding of, the capacity increases that could be realized from non-structural improvements in general. The effect of any non-structural alternative on capacity is then defined, once the effect that alternative has on locking time reduction, fleet mix, or ship utilization is defined. In addition, it would be instructive to determine the sensitivity of capacity conditions to variations in the cargo projections, recognizing the difficulty and practical limitations of making such projections, recognizing the difficulty and practical limitations of making such projections 70 years into the future. It is therefore recommended that the sensitivity analysis of non-structural improvements be expanded as follows:

a. Locking Time Reduction. Cover a 0 to 20% reduction upbound and downbound, stepping every 2%.

b. Fleet Mix. Cover several shipbuilding percentages, ranging from one that favors mostly small ships to one that favors construction of mostly large ships.

c. Cargo. The overall cargo projections would be varied ± 10 to 20%, or individual commodities which may be expecially difficult to project could be varied individually over some broad range.

d. Ship Utilization. The percentage of empty backhauls could be varied from the maximum of one for every loaded transit, to the minimum number of empty backhauls allowed by the cargo flows.

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APPENDIX A

SAMPLE OUTPUT

**** GL/SLS LOCK CAPACITY MODEL ****
**** SOO LOCK SYSTEM ****
**** 1995 ****
**** SEASON EXTENSION 3? LOCKING TIME NORM ****

**** PROJECTED CARGO TONNAGE ****
(THOUSAND SHORT TONS)

	1 APRIL			2 APRIL			MAY			JUNE			JULY		
	UP	DOWN	TOTAL	UP	DOWN	TOTAL	UP	DOWN	TOTAL	UP	DOWN	TOTAL	UP	DOWN	TOTAL
WHEAT	0	253	253	0	622	622	0	3058	3058	0	2970	2970	0	3083	3083
SOY BEANS	0	1	1	0	2	2	0	8	8	0	8	8	0	8	8
BARLEY+RYE	0	56	56	0	138	138	0	678	678	0	659	659	0	684	684
CORN	0	16	16	0	38	38	0	188	188	0	182	182	0	189	189
OIL SEED	0	14	14	0	35	35	0	173	173	0	168	168	0	175	175
LIMESTONE	23	0	23	56	0	56	275	0	275	267	0	267	277	0	277
IRON ORE	2	813	816	5	1981	1987	26	9740	9766	26	9462	9487	26	9820	9846
COAL	73	52	125	178	127	305	874	625	1499	849	607	1456	881	630	1511
RAW MATL	1	1	1	1	2	4	6	11	17	6	10	17	6	11	17
PETROLEUM	13	2	14	31	4	35	153	20	173	149	20	169	155	20	175
CEMENT	10	0	10	26	0	26	126	0	127	123	0	123	128	0	128
MINERALS	6	1	6	14	1	15	67	7	74	65	6	72	68	7	74
DRY BULK	1	21	22	3	52	54	13	254	267	13	246	259	14	256	269
GEN CARGO	8	7	15	20	17	37	99	83	182	96	81	177	100	84	184
STEEL PROD	1	3	4	2	8	10	12	38	50	12	37	49	12	38	50
TOTALS	138	1240	1376	336	3027	3364	1651	14883	16535	1606	14456	16063	1667	15005	16670

	AUGUST			SEPTEM			OCTOBER			NOVEMBER			1 DECEM		
	UP	DOWN	TOTAL	UP	DOWN	TOTAL	UP	DOWN	TOTAL	UP	DOWN	TOTAL	UP	DOWN	TOTAL
WHEAT	0	3095	3095	0	2970	2970	0	3070	3070	0	2983	2983	0	479	479
SOY BEANS	0	8	8	0	8	8	0	8	8	0	8	8	0	1	1
BARLEY+RYE	0	687	687	0	659	659	0	681	681	0	662	662	0	106	106
CORN	0	190	190	0	182	182	0	189	189	0	183	183	0	29	29
OIL SEED	0	175	175	0	168	168	0	174	174	0	169	169	0	27	27
LIMESTONE	278	0	278	267	0	267	276	0	276	268	0	268	43	0	43
IRON ORE	27	9859	9886	26	9462	9487	26	9780	9806	26	9502	9527	4	1527	1531
COAL	885	633	1517	849	607	1456	878	628	1505	853	610	1462	137	98	235
RAW MATL	6	11	17	6	10	17	6	11	17	6	11	17	1	2	3
PETROLEUM	155	20	176	149	20	169	154	20	174	150	20	169	24	3	27
CEMENT	128	0	128	123	0	123	127	0	127	123	0	124	20	0	20
MINERALS	68	7	75	65	6	72	68	7	74	66	6	72	11	1	12
DRY BULK	14	257	270	13	246	259	14	255	268	13	247	260	2	40	42
GEN CARGO	100	84	184	96	81	177	99	83	183	97	81	178	16	13	29
STEEL PROD	12	38	51	12	37	49	12	38	50	12	37	49	2	6	8
TOTALS	1673	15064	16737	1606	14456	16063	1660	14944	16602	1614	14519	16131	260	2332	2592

	2 DECEM			JANUARY			FEBRUARY			MARCH			YEAR		
	UP	DOWN	TOTAL	UP	DOWN	TOTAL	UP	DOWN	TOTAL	UP	DOWN	TOTAL	UP	DOWN	TOTAL
WHEAT	0	333	333	0	0	0	0	0	0	0	0	0	0	22916	22916
SOY BEANS	0	1	1	0	0	0	0	0	0	0	0	0	0	61	61
BARLEY+RYE	0	74	74	0	0	0	0	0	0	0	0	0	0	5084	5084
CORN	0	20	20	0	0	0	0	0	0	0	0	0	0	1406	1405
OIL SEED	0	19	19	0	0	0	0	0	0	0	0	0	0	1297	1297
LIMESTONE	30	0	30	0	0	0	0	0	0	0	0	0	2060	0	2060
IRON ORE	3	1061	1064	0	0	0	0	0	0	0	0	0	197	73007	73203
COAL	95	68	163	0	0	0	0	0	0	0	0	0	6552	4685	11234
RAW MATL	1	1	2	0	0	0	0	0	0	0	0	0	46	81	129
PETROLEUM	17	2	19	0	0	0	0	0	0	0	0	0	1150	151	1300
CEMENT	14	0	14	0	0	0	0	0	0	0	0	0	948	0	950
MINERALS	7	1	[illegible]	0	0	0	0	0	0	0	0	0	505	50	554
DRY BULK	1	20	[illegible]	0	0	0	0	0	0	0	0	0	101	1902	1999
GEN CARGO	11	9	[illegible]	0	0	0	0	0	0	0	0	0	742	623	1366
STEEL PROD	1	4	5	0	0	0	0	0	0	0	0	0	90	264	375
TOTALS	160	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

**** GL/SLS LOCK CAPACITY MODEL ****
**** SOO LOCK SYSTEM ****
**** 1985 ****
**** SEASON EXTENSION II LOCKING TIME NORM ****

**** FLEET MIX ****

CLASS	ORE NUMBER SHIPS	ORE BUILD %	COAL NUMBER SHIPS	COAL BUILD %	STONE NUMBER SHIPS	STONE BUILD %	GRAIN NUMBER SHIPS	GRAIN BUILD %	O BULK NUMBER SHIPS	O BULK BUILD %	GCARGO NUMBER SHIPS	GCARGO BUILD %	TOTAL
4	0.0	0	.4	0	.2	0	.4	0	2.5	30	1.1	20	4.6
5	19.6	10	4.2	10	.8	40	7.7	10	7.1	60	0.0	0	39.4
6	0.0	0	.8	5	0.0	0	11.1	20	0.0	0	4.4	80	16.3
7	7.8	20	1.1	40	.4	60	36.2	70	4.8	10	0.0	0	50.3
8	6.0	10	.3	15	0.0	0	0.0	0	0.0	0	0.0	0	7.1
9	1.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	1.0
10	9.4	60	1.5	30	0.0	0	0.0	0	0.0	0	0.0	0	10.9
	-----		-----		-----		-----		-----		-----		-----
TOTALS	44.6		8.3		1.4		55.4		14.4		5.5		129.6
COMPOSITE SHIP CLASS	7.0		6.3		5.4		6.5		5.5		5.6		6.5

**** VESSEL CHARACTERISTICS ****

VESSEL CLASS	VESSEL LENGTH RANGE (FT) MIN	MAX	MEAN VESSEL SPEED (MPH)	MAXIMUM CARRYING CAPACITY (S.TONS)	VESSEL UTILIZATION (%)	LOCKING TIME (MIN) UP	DN	CAPACITY INCREASE WITH DRAFT (ST/IN)
3	(PLEASURE CRAFT, NON-COMMERCIAL VESSELS, AND ICE LOCKAGES)							
4	0	599	13.8	9500	80	68	73	0.0
5	600	699	13.9	21000	80	65	75	91.8
6	400	699	14.7	15000	80	65	74	61.8
7	700	749	14.7	27000	80	61	77	113.1
8	750	849	14.9	28000	80	68	78	115.6
9	850	989	14.9	45000	80	73	101	167.1
10	990	1099	14.9	60000	80	89	106	207.1

CLASS 5 IS LAKERS OF CLASSES 5 AND 6
CLASS 6 IS OCEAN GOING VESSELS

**** GL/SLS LOCK CAPACITY MODEL ****
**** SOO LOCK SYSTEM ****
**** 1985 ****
**** SEASON EXTENSION 17 LOCKING TIME NORM ****

***** YEARLY TRANSITS BY COMMODITY AND CLASS *****

LOADED TRANSITS

CLASS	ORE UP	ORE DN	COAL UP	COAL DN	STONE UP	STONE DN	GRAIN UP	GRAIN DN	OTHER BULK UP	OTHER BULK DN	GEN CARGO UP	GEN CARGO DN
4	0	0	22	14	14	0	0	14	58	45	22	23
5	0	1035	144	102	53	0	0	232	106	83	0	0
6	0	0	30	22	0	0	0	352	0	0	53	58
7	0	423	35	23	30	0	0	1051	61	46	0	0
8	0	361	7	7	0	0	0	0	0	0	0	0
9	0	50	0	0	0	0	0	0	0	0	0	0
10	0	461	50	38	0	0	0	0	0	0	0	0
TOTAL	0	2330	288	206	97	0	0	1649	225	174	75	81

CLASS	LOADED TRANSITS TOTAL UP	LOADED TRANSITS TOTAL DN	LOADED TRANSITS TOTAL TOTAL	BALLASTED TRANSITS TOTAL UP	BALLASTED TRANSITS TOTAL DN	BALLASTED TRANSITS TOTAL TOTAL	TOTAL ALL UP	TOTAL ALL DN	TOTAL ALL TOTAL
4	116	96	212	20	36	56	136	132	268
5	303	1452	1755	1198	61	1259	1501	1513	3014
6	83	432	515	359	16	375	442	448	890
7	126	1543	1669	1426	25	1451	1552	1568	3120
8	7	368	375	354	2	356	361	370	731
9	0	50	50	48	0	48	48	50	98
10	50	499	549	448	10	458	498	509	1007
TOTAL	685	4440	5125	3853	150	4003	4538	4570	9120

GL/GLS LOCK CAPACITY MODEL

SOO LOCK SYSTEM

1985

SEASON EXTENSION 1F LOCKING TIME NORM

DAILY TRANSIT DEMAND BY MONTH AND CLASS

1 APRIL

CLASS	UP LOAD	UP BLST	UP TOTAL	DN LOAD	DN BLST	DN TOTAL	TOTAL LOAD	TOTAL BLST	TOTAL TOTAL
3	0.0	0.0	0.0	0.0	1.0	1.0	0.0	1.0	1.0
4	.1	0.0	.1	.1	0.0	.1	.2	0.0	.2
5	.2	1.3	1.5	1.1	0.0	1.1	1.3	1.3	2.6
6	.1	.4	.5	.3	0.0	.3	.4	.4	.8
7	.1	1.6	1.7	1.1	0.0	1.1	1.2	1.6	2.8
8	0.0	.4	.4	.3	0.0	.3	.3	.4	.7
9	0.0	.1	.1	0.0	0.0	0.0	0.0	.1	.1
10	0.0	.5	.5	.4	0.0	.4	.4	.5	.9
TOTAL	.5	4.3	4.8	3.3	1.0	4.3	3.8	5.3	9.1

2 APRIL

CLASS	UP LOAD	UP BLST	UP TOTAL	DN LOAD	DN BLST	DN TOTAL	TOTAL LOAD	TOTAL BLST	TOTAL TOTAL
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	.2	0.0	.2	.2	.1	.3	.4	.1	.5
5	.6	2.6	3.2	2.6	.1	2.7	3.2	2.7	5.9
6	.1	.8	.9	.8	0.0	.8	.9	.8	1.7
7	.2	3.1	3.3	2.8	0.0	2.8	3.0	3.1	6.1
8	0.0	.8	.8	.7	0.0	.7	.7	.8	1.5
9	0.0	.1	.1	.1	0.0	.1	.1	.1	.2
10	.1	1.0	1.1	.9	0.0	.9	1.0	1.0	2.0
TOTAL	1.2	8.4	9.6	8.1	.2	8.3	9.3	8.6	17.9

MAY

CLASS	UP LOAD	UP BLST	UP TOTAL	DN LOAD	DN BLST	DN TOTAL	TOTAL LOAD	TOTAL BLST	TOTAL TOTAL
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	.5	.1	.6	.4	.2	.6	.9	.3	1.2
5	1.3	5.2	6.5	6.3	.3	6.6	7.6	5.5	13.1
6	.3	1.6	1.9	1.8	.1	1.9	2.1	1.7	3.8
7	.5	6.2	6.7	6.7	.1	6.8	7.2	6.3	13.5
8	0.0	1.5	1.5	1.6	0.0	1.6	1.6	1.5	3.1
9	0.0	.2	.2	.2	0.0	.2	.2	.2	.4
10	.2	2.0	2.2	2.1	0.0	2.1	2.3	2.0	4.3
TOTAL	2.8	16.8	19.6	19.1	.7	19.8	21.9	17.5	39.4

JUNE

CLASS	UP LOAD	UP BLST	UP TOTAL	DN LOAD	DN BLST	DN TOTAL	TOTAL LOAD	TOTAL BLST	TOTAL TOTAL
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	.5	.1	.6	.4	.2	.6	.9	.3	1.2
5	1.3	5.2	6.5	6.3	.3	6.6	7.6	5.5	13.1
6	.4	1.6	2.0	1.9	.1	2.0	2.3	1.7	4.0
7	.5	6.2	6.7	6.7	.1	6.8	7.2	6.3	13.5
8	0.0	1.5	1.5	1.6	0.0	1.6	1.6	1.5	3.1
9	0.0	.2	.2	.2	0.0	.2	.2	.2	.4
10	.2	2.0	2.2	2.1	0.0	2.1	2.3	2.0	4.3
TOTAL	2.9	16.8	19.7	19.2	.7	19.9	22.1	17.5	39.6

JULY

CLASS	UP LOAD	UP BLST	UP TOTAL	DN LOAD	DN BLST	DN TOTAL	TOTAL LOAD	TOTAL BLST	TOTAL TOTAL
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	.5	.1	.6	.4	.2	.6	.9	.3	1.2
5	1.3	5.3	6.6	6.3	.3	6.6	7.6	5.6	13.2
6	.4	1.6	2.0	1.9	.1	2.0	2.3	1.7	4.0
7	.5	6.3	6.8	6.7	.1	6.8	7.2	6.4	13.6
8	0.0	1.6	1.6	1.6	0.0	1.6	1.6	1.6	3.2
9	0.0	.2	.2	.2	0.0	.2	.2	.2	.4
10	.2	2.0	2.2	2.1	0.0	2.1	2.3	2.0	4.3
TOTAL	2.9	17.1	20.0	19.2	.7	19.9	22.1	17.8	39.9

AUGUST

CLASS	UP LOAD	UP BLST	UP TOTAL	DN LOAD	DN BLST	DN TOTAL	TOTAL LOAD	TOTAL BLST	TOTAL TOTAL
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	.5	.1	.6	.4	.2	.6	.9	.3	1.2
5	1.3	5.3	6.6	6.3	.3	6.6	7.6	5.6	13.2
6	.4	1.6	2.0	1.9	.1	2.0	2.3	1.7	4.0
7	.5	6.3	6.8	6.7	.1	6.8	7.2	6.4	13.6
8	0.0	1.6	1.6	1.6	0.0	1.6	1.6	1.6	3.2
9	0.0	.2	.2	.2	0.0	.2	.2	.2	.4
10	.2	2.0	2.2	2.2	0.0	2.2	2.4	2.0	4.4
TOTAL	2.9	17.1	20.0	19.3	.7	20.0	22.2	17.8	40.0

**** GL/SLS LOCK CAPACITY MODEL ****
**** SOO LOCK SYSTEM ****
**** 1985 ****
**** SEASON EXTENSION II LOCKING TIME NORM ****

**** DAILY TRANSIT DEMAND BY MONTH AND CLASS ****
CONTINUED

SEPTEM

	UP			DN			TOTAL		
CLASS	LOAD	BLST	TOTAL	LOAD	BLST	TOTAL	LOAD	BLST	TOTAL
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	.5	.1	.6	.4	.2	.6	.9	.3	1.2
5	1.3	5.2	6.5	6.3	.3	6.6	7.6	5.5	13.1
6	.4	1.6	2.0	1.9	.1	2.0	2.3	1.7	4.0
7	.5	6.2	6.7	6.7	.1	6.8	7.2	6.3	13.5
8	0.0	1.5	1.5	1.6	0.0	1.6	1.6	1.5	3.1
9	0.0	.2	.2	.2	0.0	.2	.2	.2	.4
10	.2	2.0	2.2	2.1	0.0	2.1	2.3	2.0	4.3
TOTAL	2.9	16.8	19.7	19.2	.7	19.9	22.1	17.5	39.6

OCTOBER

	UP			DN			TOTAL		
CLASS	LOAD	BLST	TOTAL	LOAD	BLST	TOTAL	LOAD	BLST	TOTAL
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	.5	.1	.6	.4	.2	.6	.9	.3	1.2
5	1.3	5.2	6.5	6.3	.3	6.6	7.6	5.5	13.1
6	.4	1.6	2.0	1.9	.1	2.0	2.3	1.7	4.0
7	.5	6.2	6.7	6.7	.1	6.8	7.2	6.3	13.5
8	0.0	1.5	1.5	1.6	0.0	1.6	1.6	1.5	3.1
9	0.0	.2	.2	.2	0.0	.2	.2	.2	.4
10	.2	2.0	2.2	2.1	0.0	2.1	2.3	2.0	4.3
TOTAL	2.9	16.6	19.7	19.2	.7	19.9	22.1	17.5	39.6

NOVEMBER

	UP			DN			TOTAL		
CLASS	LOAD	BLST	TOTAL	LOAD	BLST	TOTAL	LOAD	BLST	TOTAL
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	.5	.1	.6	.4	.2	.6	.9	.3	1.2
5	1.3	5.3	6.6	6.3	.3	6.6	7.6	5.6	13.2
6	.4	1.6	2.0	1.9	.1	2.0	2.3	1.7	4.0
7	.5	6.3	6.8	6.7	.1	6.8	7.2	6.4	13.6
8	0.0	1.6	1.6	1.6	0.0	1.6	1.6	1.6	3.2
9	0.0	.2	.2	.2	0.0	.2	.2	.2	.4
10	.2	2.0	2.2	2.1	0.0	2.1	2.3	2.0	4.3
TOTAL	2.9	17.1	20.0	19.2	.7	19.9	22.1	17.8	39.9

1 DECEM

	UP			DN			TOTAL		
CLASS	LOAD	BLST	TOTAL	LOAD	BLST	TOTAL	LOAD	BLST	TOTAL
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	.2	0.0	.2	.1	0.0	.1	.3	0.0	.3
5	.4	.7	1.1	2.0	.1	2.1	2.4	.8	3.2
6	.1	.2	.3	.6	0.0	.6	.7	.2	.9
7	.2	.8	1.0	2.2	0.0	2.2	2.4	.8	3.2
8	0.0	.2	.2	.5	0.0	.5	.5	.2	.7
9	0.0	0.0	0.0	.1	0.0	.1	.1	0.0	.1
10	.1	.3	.4	.7	0.0	.7	.8	.3	1.1
TOTAL	1.0	2.2	3.2	6.2	.1	6.3	7.2	2.3	9.5

2 DECEM

	UP			DN			TOTAL		
CLASS	LOAD	BLST	TOTAL	LOAD	BLST	TOTAL	LOAD	BLST	TOTAL
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	.1	0.0	.1	.1	0.0	.1	.2	0.0	.2
5	.3	.2	.5	1.4	.1	1.5	1.7	.3	2.0
6	.1	.1	.2	.4	0.0	.4	.5	.1	.6
7	.1	.3	.4	1.5	0.0	1.5	1.6	.3	1.9
8	0.0	.1	.1	.4	0.0	.4	.4	.1	.5
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	.1	.1	.5	0.0	.5	.5	.1	.6
TOTAL	.6	.8	1.4	4.3	.1	4.4	4.9	.9	5.8

JANUARY

	UP			DN			TOTAL		
CLASS	LOAD	BLST	TOTAL	LOAD	BLST	TOTAL	LOAD	BLST	TOTAL
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

**** GL/SLS LOCK CAPACITY MODEL ****
**** SOO LOCK SYSTEM ****
**** 1995 ****
**** SEASON EXTENSION II LOCKING TIME NORM ****

**** DAILY TRANSIT DEMAND BY MONTH AND CLASS ****
CONTINUED

	FEBRUARY									MARCH								
	UP			DN			TOTAL			UP			DN			TOTAL		
CLASS	LOAD	BLST	TOTAL	LOAD	BLST	TOTAL	LOAD	BLST	TOTAL	LOAD	BLST	TOTAL	LOAD	BLST	TOTAL	LOAD	BLST	TOTAL
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

**** GLZSLS LOCK CAPACITY MODEL ****
**** SOO LOCK SYSTEM ****
**** 1985 ****
**** SEASON EXTENSION 17 LOCKING TIME NORM ****

**** ACTUAL TRANSITS ****

1 APRIL

CLASS	MACARTHUR UP	MACARTHUR DN	MACARTHUR TOTAL	POE UP	POE DN	POE TOTAL	SABIN AND DAVIS UP	SABIN AND DAVIS DN	SABIN AND DAVIS TOTAL
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	.1	.1	.2
5	.2	.7	.9	0.0	.3	.3	1.3	0.0	1.3
6	.1	.2	.3	0.0	.1	.1	.4	0.0	.4
7	.1	.8	.9	0.0	.4	.4	1.6	0.0	1.6
8	0.0	0.0	0.0	0.0	.3	.3	.4	0.0	.4
9	0.0	0.0	0.0	.1	0.0	.1	0.0	0.0	0.0
10	0.0	0.0	0.0	.5	.4	1.0	0.0	0.0	0.0
TOTAL	.4	1.7	2.1	.7	1.5	2.2	3.8	.1	3.9

2 APRIL

CLASS	MACARTHUR UP	MACARTHUR DN	MACARTHUR TOTAL	POE UP	POE DN	POE TOTAL	SABIN AND DAVIS UP	SABIN AND DAVIS DN	SABIN AND DAVIS TOTAL
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	.3	.2	.5
5	.6	1.8	2.4	0.0	.8	.8	2.6	.1	2.7
6	.1	.5	.6	0.0	.2	.2	.8	0.0	.8
7	.2	1.9	2.1	0.0	.9	.9	3.1	0.0	3.1
8	0.0	0.0	0.0	0.0	.7	.7	.8	0.0	.8
9	0.0	0.0	0.0	.1	.1	.2	0.0	0.0	0.0
10	0.0	0.0	0.0	1.1	.9	2.0	0.0	0.0	0.0
TOTAL	.9	4.2	5.1	1.2	3.6	4.8	7.6	.3	7.9

MAY

CLASS	MACARTHUR UP	MACARTHUR DN	MACARTHUR TOTAL	POE UP	POE DN	POE TOTAL	SABIN AND DAVIS UP	SABIN AND DAVIS DN	SABIN AND DAVIS TOTAL
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	.6	.6	1.2
5	1.3	4.3	5.6	0.0	1.9	1.9	5.2	.3	5.5
6	.3	1.3	1.6	0.0	.6	.6	1.6	.1	1.7
7	.5	4.5	5.1	0.0	2.0	2.0	6.2	.1	6.3
8	0.0	0.0	0.0	0.0	1.5	1.5	1.5	0.0	1.5
9	0.0	0.0	0.0	.2	.2	.4	0.0	0.0	0.0
10	0.0	0.0	0.0	2.2	2.2	4.4	0.0	0.0	0.0
TOTAL	2.1	10.2	12.3	2.4	8.5	10.9	15.1	1.1	16.2

JUNE

CLASS	MACARTHUR UP	MACARTHUR DN	MACARTHUR TOTAL	POE UP	POE DN	POE TOTAL	SABIN AND DAVIS UP	SABIN AND DAVIS DN	SABIN AND DAVIS TOTAL
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	.6	.6	1.2
5	1.3	4.4	5.7	0.0	1.9	1.9	5.2	.3	5.5
6	.4	1.3	1.7	0.0	.6	.6	1.6	.1	1.7
7	.5	4.6	5.1	0.0	2.1	2.1	6.2	.1	6.3
8	0.0	0.0	0.0	0.0	1.6	1.6	1.5	0.0	1.5
9	0.0	0.0	0.0	.2	.2	.4	0.0	0.0	0.0
10	0.0	0.0	0.0	2.2	2.2	4.4	0.0	0.0	0.0
TOTAL	2.2	10.3	12.5	2.4	8.6	11.0	15.1	1.1	16.2

JULY

CLASS	MACARTHUR UP	MACARTHUR DN	MACARTHUR TOTAL	POE UP	POE DN	POE TOTAL	SABIN AND DAVIS UP	SABIN AND DAVIS DN	SABIN AND DAVIS TOTAL
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	.6	.6	1.2
5	1.3	4.4	5.7	0.0	1.9	1.9	5.3	.3	5.6
6	.4	1.3	1.7	0.0	.5	.6	1.6	.1	1.7
7	.5	4.5	5.1	0.0	2.1	2.1	6.3	.1	6.4
8	0.0	0.0	0.0	0.0	1.5	1.6	1.6	0.0	1.6
9	0.0	0.0	0.0	.2	.2	.4	0.0	0.0	0.0
10	0.0	0.0	0.0	2.2	2.2	4.4	0.0	0.0	0.0

AUGUST

CLASS	MACARTHUR UP	MACARTHUR DN	MACARTHUR TOTAL	POE UP	POE DN	POE TOTAL	SABIN AND DAVIS UP	SABIN AND DAVIS DN	SABIN AND DAVIS TOTAL
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	.6	.6	1.2
5	1.3	4.4	5.7	0.0	2.0	2.0	5.3	.3	5.6
6	.4	1.3	1.7	0.0	.6	.6	1.6	.1	1.7
7	.5	4.7	5.2	0.0	2.1	2.1	6.3	.1	6.4
8	0.0	0.0	0.0	0.0	1.6	1.6	1.6	0.0	1.6
9	0.0	0.0	0.0	.2	.2	.4	0.0	0.0	0.0
10	0.0	0.0	0.0	2.2	2.2	4.4	0.0	0.0	0.0

**** GL/SLS LOCK CAPACITY MODEL ****
**** SOO LOCK SYSTEM ****
**** 1995 ****
**** SEASON EXTENSION 1, LOCKING TIME NORM ****

**** ACTUAL TRANSITS ****
CONTINUED

	SEPTEM									OCTOBER								
	MACARTHUR			POE			SABIN AND DAVIS			MACARTHUR			POE			SABIN AND DAVIS		
CLASS	UP	DN	TOTAL	UP	DN	TOTAL	UP	DN	TOTAL	UP	DN	TOTAL	UP	DN	TOTAL	UP	DN	TOTAL
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	.6	.6	1.2	0.0	0.0	0.0	0.0	0.0	0.0	.6	.6	1.2
5	1.3	4.4	5.7	0.0	1.9	1.9	5.2	.3	5.5	1.3	4.4	5.7	0.0	1.9	1.9	5.2	.3	5.5
6	.4	1.3	1.7	0.0	.6	.6	1.6	.1	1.7	.4	1.3	1.7	0.0	.6	.6	1.6	.1	1.7
7	.5	4.6	5.1	0.0	2.1	2.1	6.2	.1	6.3	.5	4.6	5.1	0.0	2.1	2.1	6.2	.1	6.3
8	0.0	0.0	0.0	0.0	1.6	1.6	1.5	0.0	1.5	0.0	0.0	0.0	0.0	1.6	1.6	1.5	0.0	1.5
9	0.0	0.0	0.0	.2	.2	.4	0.0	0.0	0.0	0.0	0.0	0.0	.2	.2	.4	0.0	0.0	0.0
10	0.0	0.0	0.0	2.2	2.2	4.4	0.0	0.0	0.0	0.0	0.0	0.0	2.2	2.2	4.4	0.0	0.0	0.0
TOTAL	2.2	10.3	12.5	2.4	8.6	11.0	15.1	1.1	16.2	2.2	10.3	12.5	2.4	8.6	11.0	15.1	1.1	16.2

	NOVEMBER									1 DECEM								
	MACARTHUR			POE			SABIN AND DAVIS			MACARTHUR			POE			SABIN AND DAVIS		
CLASS	UP	DN	TOTAL	UP	DN	TOTAL	UP	DN	TOTAL	UP	DN	TOTAL	UP	DN	TOTAL	UP	DN	TOTAL
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	.6	.6	1.2	0.0	0.0	0.0	0.0	0.0	0.0	.2	.2	.4
5	1.3	4.4	5.7	0.0	1.9	1.9	5.3	.3	5.6	.4	1.4	1.8	.1	.7	.8	.7	.1	.8
6	.4	1.3	1.7	0.0	.5	.5	1.6	.1	1.7	.1	.4	.5	0.0	.2	.2	.2	0.0	.2
7	.5	4.6	5.1	0.0	2.1	2.1	6.3	.1	6.4	.1	1.4	1.5	0.0	.7	.7	.8	0.0	.8
8	0.0	0.0	0.0	0.0	1.6	1.6	1.6	0.0	1.6	0.0	0.0	0.0	0.0	.5	.5	.2	0.0	.2
9	0.0	0.0	0.0	.2	.2	.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.1	.1	0.0	0.0	0.0
10	0.0	0.0	0.0	2.2	2.2	4.4	0.0	0.0	0.0	0.0	0.0	0.0	.3	.7	1.0	0.0	0.0	0.0
TOTAL	2.2	10.3	12.5	2.4	8.5	11.0	15.4	1.1	16.5	.6	3.2	3.8	.4	2.9	3.3	2.1	.3	2.4

	2 DECEM									JANUARY								
	MACARTHUR			POE			SABIN AND DAVIS			MACARTHUR			POE			SABIN AND DAVIS		
CLASS	UP	DN	TOTAL	UP	DN	TOTAL	UP	DN	TOTAL	UP	DN	TOTAL	UP	DN	TOTAL	UP	DN	TOTAL
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	.1	.1	.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	.2	.9	1.1	.1	.5	.6	.2	.1	.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	.1	.3	.4	0.0	.1	.1	.1	0.0	.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	.1	1.0	1.1	0.0	.5	.5	.3	0.0	.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	.4	.4	.1	0.0	.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	.1	.5	.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	.4	2.2	2.6	.2	2.0	2.2	.8	.2	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

**** GL/SLS LOCK CAPACITY MODEL ****
**** SOO LOCK SYSTEM ****
**** 1985 ****
**** SEASON EXTENSION II LOCKING TIME NORM ****

**** ACTUAL TRANSITS ****
CONTINUED

	FEBRUARY									MARCH								
	MACARTHUR			POE			SABIN AND DAVIS			MACARTHUR			POE			SABIN AND DAVIS		
CLASS	UP	DN	TOTAL	UP	DN	TOTAL	UP	DN	TOTAL	UP	DN	TOTAL	UP	DN	TOTAL	UP	DN	TOTAL
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

**** GL/SLS LOCK CAPACITY MODEL ****
**** SOO LOCK SYSTEM ****
**** 1985 ****
**** SEASON EXTENSION II LOCKING TIME NORM ****

**** QUEUING INFORMATION ****

**** MACARTHUR LOCK ****

	1 APRIL UP	DN	2 APRIL UP	DN	MAY UP	DN	JUNE UP	DN	JULY UP	DN	AUGUST UP	DN	SEPTEM UP	DN
LOCK OPERATION TIME (HRS)	356		356		735		714		741		744		714	
LOCK CYCLE TIME (MIN): MEAN	78	85	82	79	110	88	110	88	110	88	110	88	110	88
: ST DEV	10	8	10	7	10	7	10	7	10	7	10	7	10	7
AVE.WAITING TIME (HOURS)	.05	.08	.04	.21	.19	1.25	.19	1.25	.19	1.25	.19	1.25	.19	1.25
MONTHLY WAITING TIME (HRS)	0	2	1	13	12	396	13	387	13	400	13	403	13	387
AVE. QUEUE LENGTH (SHIPS)	.00	.01	.00	.04	.02	.54	.02	.54	.02	.54	.02	.54	.02	.54
LOCK UTILIZATION (%)	10		24		63		63		63		63		63	

	OCTOBER UP	DN	NOVEMBER UP	DN	1 DECEM UP	DN	2 DECEM UP	DN	JANUARY UP	DN	FEBRUARY UP	DN	MARCH UP	DN
LOCK OPERATION TIME (HRS)	738		717		360		384		0		0		0	
LOCK CYCLE TIME (MIN): MEAN	110	88	110	88	77	78	77	81	0	0	0	0	0	0
: ST DEV	10	7	10	7	10	7	10	8	0	0	0	0	0	0
AVE.WAITING TIME (HOURS)	.19	1.25	.19	1.25	.02	.14	.01	.10	0.00	0.00	0.00	0.00	0.00	0.00
MONTHLY WAITING TIME (HRS)	13	400	13	387	0	7	0	3	0	0	0	0	0	0
AVE. QUEUE LENGTH (SHIPS)	.02	.54	.02	.54	.00	.02	.00	.01	0.00	0.00	0.00	0.00	0.00	0.00
LOCK UTILIZATION (%)	63		63		17		13		0		0		0	

YEARLY WAITING TIME (HOURS) UPBOUND: 90. DOWNBOUND: 2704.

**** POE LOCK ****

	1 APRIL UP	DN	2 APRIL UP	DN	MAY UP	DN	JUNE UP	DN	JULY UP	DN	AUGUST UP	DN	SEPTEM UP	DN
LOCK OPERATION TIME (HRS)	356		356		735		714		741		744		714	
LOCK CYCLE TIME (MIN): MEAN	88	97	107	92	141	105	141	105	141	105	141	105	141	105
: ST DEV	14	15	10	14	13	15	13	15	13	15	13	15	13	15
AVE.WAITING TIME (HOURS)	.08	.09	.09	.24	.38	1.52	.38	1.52	.38	1.52	.30	1.52	.38	1.52
MONTHLY WAITING TIME (HRS)	1	2	2	13	28	401	27	392	28	406	20	410	27	392
AVE. QUEUE LENGTH (SHIPS)	.01	.01	.00	.04	.04	.55	.04	.55	.04	.55	.04	.55	.04	.55
LOCK UTILIZATION (%)	10		24		63		63		63		63		63	

	OCTOBER UP	DN	NOVEMBER UP	DN	1 DECEM UP	DN	2 DECEM UP	DN	JANUARY UP	DN	FEBRUARY UP	DN	MARCH UP	DN
LOCK OPERATION TIME (HRS)	738		717		360		384		0		0		0	
LOCK CYCLE TIME (MIN): MEAN	141	105	141	105	96	87	91	90	0	0	0	0	0	0
: ST DEV	13	15	13	15	14	14	15	15	0	0	0	0	0	0
AVE.WAITING TIME (HOURS)	.38	1.52	.38	1.52	.03	.16	.02	.11	0.00	0.00	0.00	0.00	0.00	0.00
MONTHLY WAITING TIME (HRS)	28	406	27	392	0	7	0	3	0	0	0	0	0	0
AVE. QUEUE LENGTH (SHIPS)	.04	.55	.04	.55	.00	.02	.00	.01	0.00	0.00	0.00	0.00	0.00	0.00
LOCK UTILIZATION (%)	63		63		17		13		0		0		0	

YEARLY WAITING TIME (HOURS) UPBOUND: 196. DOWNBOUND: 2824.

**** SABIN AND DAVIS LOCKS ****

	1 APRIL UP	DN	2 APRIL UP	DN	MAY UP	DN	JUNE UP	DN	JULY UP	DN	AUGUST UP	DN	SEPTEM UP	DN
LOCK OPERATION TIME (HRS)	356		356		735		714		741		744		714	
LOCK CYCLE TIME (MIN): MEAN	45	49	44	51	45	61	45	61	45	61	45	61	45	61
: ST DEV	5	4	4	4	4	4	4	4	4	4	4	4	4	4
AVE.WAITING TIME (HOURS)	[illegible]	.00	.11	.01	.35	.02	.35	.02	.35	.02	.35	.02	.35	.02
MONTHLY WAITING TIME (HRS)	4	0	13	0	163	1	158	1	166	1	166	1	158	1
AVE. QUEUE LENGTH (SHIPS)	[illegible]	.00	.04	.00	.22	.00	.22	.00	.22	.00	.22	.00	.22	.00
LOCK UTILIZATION (%)	15		23		48		48		48		48		48	

	OCTOBER UP	DN	NOVEMBER UP	DN	1 DECEM UP	DN	2 DECEM UP	DN	JANUARY UP	DN	FEBRUARY UP	DN	MARCH UP	DN
LOCK OPERATION TIME (HRS)	738		717		360		384		0		0		0	
LOCK CYCLE TIME (MIN): MEAN	45	61	45	61	43	43	45	44	0	0	0	0	0	0
: ST DEV	4	4	4	4	4	4	5	4	0	0	0	0	0	0
AVE.WAITING TIME (HOURS)	.35	.02	.35	.02	.02	.00	.01	.00	0.00	0.00	0.00	0.00	0.00	0.00
MONTHLY WAITING TIME (HRS)	163	1	161	1	1	0	0	0	0	0	0	0	0	0
AVE. QUEUE LENGTH (SHIPS)	.22	[illegible]	.22	.00	.00	.00	.00	.00	0.00	0.00	0.00	0.00	0.00	0.00
LOCK UTILIZATION (%)	48		48		6		2		0		0		0	

YEARLY WAITING TIME (HOURS) UPBOUND: 1151. DOWNBOUND: 6.

ACTUAL CARGO FLOW BY COMMODITY AND MONTH

CARGO	1 APR	2 APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	1 DEC	2 DEC	JAN	FEB	MARCH	TOTAL
WHEAT	253	622	3050	2970	3083	3095	2970	3070	2983	479	333	0	0	0	22916
SOY BEAN	1	2	8	8	8	8	8	8	8	1	1	0	0	0	61
[illegible]	56	138	670	659	684	687	659	681	662	106	74	0	0	0	5084
CORN	16	38	188	182	189	190	182	189	183	29	20	0	0	0	1406
OIL SEED	14	35	173	168	175	175	168	174	169	27	19	0	0	0	1297
LIVESTK	23	56	275	267	277	278	267	276	268	43	30	0	0	0	2060
[illegible] OIL	816	1987	9766	9407	9846	9886	9407	9806	9527	1531	1064	0	0	0	73203
COAL	125	305	1499	1456	1511	1517	1456	1505	1462	235	163	0	0	0	11234
RAW MATL	1	4	17	17	17	17	17	17	17	3	2	0	0	0	129
[illegible]	14	35	173	169	175	176	169	174	169	27	19	0	0	0	1300
CEMENT	10	26	127	123	128	128	123	127	124	20	14	0	0	0	950
MINERAL	6	15	74	72	74	75	72	74	72	12	8	0	0	0	554
DRY BULK	22	54	267	259	269	270	259	268	260	42	29	0	0	0	1799
GEN CARG	15	37	182	177	184	184	177	183	178	29	20	0	0	0	1366
STL PROD	4	10	50	49	50	51	49	50	49	8	5	0	0	0	375
TOTAL	1376	3384	16535	16063	16670	16737	16063	16602	16131	2592	1801	0	0	0	123934

DATE
ILME